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TEN-YEAR AGING OF ELASTOMERIC VULCANIZATES IN PANAMA, ALASKA, AND ILLINOIS

Edward W. Bergstrom

JULY 1974

TECHNICAL REPORT

RESEARCH DIRECTORATE

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3. Outdoor Aging
4. Ozone Resistance
5. Exposure Cracking
6. Antiozonants
7. Properties, General

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Vulcanizates prepared from commercially available elastomers, many of which have been introduced since 1955, were exposed outdoors in Alaska; Rock Island, Illinois; and in the Panama Canal Zone to compare the effects of exposure in arctic, temperate, and tropic environments. Aging data collected on pads exposed as long as ten years are presented. The effects of rain forest vs.

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20. ABSTRACT

open sun exposure in Panama are compared as well as the effects of indoor vs. outdoor aging at Rock Island, Illinois.

The ozone resistance of numerous vulcanizates was determined by exposures at the three sites, using ASTM D518, Method B, bent loop specimens. The resistance to cracking of numerous polyurethane vulcanizates exposed in Panama was also measured.

Results show that aging is generally more severe in Panama than in Alaska or Rock Island, although some vulcanizates exhibit excellent aging resistance at all three sites.

Polymeric antiozonants (EPLM) are more effective than chemical antiozonants in protecting SBR, NBR, and NR vulcanizates from ozone attack.

Unstressed polyester urethane vulcanizates, even those containing hydrolysis inhibitors, deteriorate rapidly in Panama. Polyether urethane vulcanizates have also begun to show significant deterioration in Panama after seven years, while polyether urethane-urea vulcanizates remain relatively unaffected.

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OBJECTIVE

The objective of this work was to compare the effects of arctic, tropic, and temperate environments on the properties of vulcanizates prepared from commercially available elastomers.

BACKGROUND

This program was initiated in 1961 to determine the effects of environmental conditions on rubber vulcanizates since rubber end-items prepared for military use may be subjected to all types of climatic conditions. An aging program of this type was considered to be essential since these data were lacking on many elastomers. Reports covering the results of two years[1] and five years[2] of aging on numerous vulcanizates at arctic, temperate, and tropic test sites have been issued. This report covers the results of further aging of these compounds plus the results for vulcanizates placed in test since 1968.

APPROACH

The first group of 6 inch by 6 inch by .080 inch test pads of rubber vulcanizates selected for this program were exposed outdoors in December 1961 at Rock Island, Illinois, on racks set at an angle of 45 degrees facing south. Bent loop ozone specimens (ASTM D518, Method B) of various antiozonant-inhibited vulcanizates were also exposed. Additional pads and bent loop specimens have been placed in test since that time. At intervals of two, four, six, eight, and ten years, one pad of each compound was removed from test and physical properties were determined. The bent loop ozone specimens were checked weekly for the first month, monthly up to the first year and semi-annually thereafter.

Exposure tests were begun at Fort Wainwright, Alaska, in August 1962, through arrangements made with the U.S. Army Ordnance Development and Proof Services, Aberdeen Proving Ground, Maryland. Subsequent tests were arranged with the U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland. Pads and bent loop specimens were prepared at Rock Island and shipped to Alaska where they were placed in test by U.S. Army Arctic Test Center personnel. In July 1966, the test site was moved from Fort Wainwright to Fort Greely, Alaska, and all pads and bent loop specimens were moved to the latter site. One test pad of each compound was removed from test at periodic intervals and returned to this laboratory for testing. The bent loop specimens were checked by Test Center personnel at the time the pads were removed from test. Local climatological data for the area were also received.

---

[1] Bergstrom, E.W., "Two-Year Aging of Elastomeric Vulcanizates in Panama, Alaska, and Illinois", Technical Report 65-2374, AD626697, September 1965.

[2] Bergstrom, E.W., "Five-Year Aging of Elastomeric Vulcanizates in Panama, Alaska, and Illinois", Technical Report 68-3462, AD849345L, December 1968.

Pads and looped specimens of numerous rubber compounds were exposed in the Panama Canal Zone beginning in February 1963 through arrangements made with the Protective and Preservation Section, Frankford Arsenal, Philadelphia, Pa. Subsequent exposure tests have been coordinated with Dr. Leonard Teitell of the Pitman-Dunn Research Laboratories, Frankford Arsenal. Two main exposure sites in Panama were utilized, (1) open field (no shade) and (2) rain forest (densely wooded, high humidity and high fungus). The cloud forest site mentioned in earlier reports[1,2] has been abandoned. Specimens were also exposed in the shade (close by open field site) and in a hut next to the rain forest to determine the effects of various tropical conditions on rubber vulcanizates. One test pad of each compound was returned from the various sites at periodic intervals, and reports of observations made on bent loop specimens were forwarded to this laboratory. Local climatological data for the various sites were also received. A report[3] giving a detailed description of the Panamanian test sites and climatological data for each site is available.

Test pads of several of the same compounds exposed outdoors in Panama, Alaska, and at this installation are also being shelf-aged at this location so that a comparison of indoor vs. outdoor exposure can be made.

Accelerated air oven-aging tests were run on most vulcanizates at either 212°F or 400°F (depending upon the heat resistance of the vulcanizate) so that a comparison could be made of accelerated vs. outdoor aging.

Compound formulations are given in Table 1. Compounding, mixing, curing, and testing were done in accordance with ASTM procedures, where applicable.

RESULTS AND DISCUSSION

The changes in tensile strength and elongation of vulcanizates aged outdoors in the open sun at Rock Island, Illinois, Alaska, and Panama, are shown graphically in Figures 1 through 9. (Detailed physical property results are given in Appendix A). These graphs show that, in general, aging in Panama is more severe than aging in Alaska or at Rock Island, Illinois, although vulcanizates based on EPR 404, Chlorobutyl HT 1066, Viton B, Nordel 1070, and EPT 3509 exhibited excellent aging resistance at all three sites. In the opinion of this laboratory, elongation or strain are better criteria for determining the aging characteristics of most vulcanizates than are changes in tensile strength or hardness. The only exceptions to this are found with the cis polyisoprene (A21D), Hycar 4021 (Z47F), and Genthane SR (Z60D4) vulcanizates where tensile strength deterioration is the best criterion of the change which takes place during aging. Both the ethyl acrylate/chloroethyl vinyl ether (Hycar 4021) and polyester urethane (Genthane SR) vulcanizates are subject to hydrolytic decomposition and, therefore, tensile strength deteriorates very rapidly in areas of high humidity such as Panama.

---

[1] Bergstrom, E.W., Ibid.
[2] Bergstrom, E.W., Ibid.
[3] Frankford Arsenal Report R-1888, "Studies of the Effects of Tropical Environments in Materials I. Description of Exposure Sites", May 1968.

Table 1
COMPOUND FORMULATIONS (Parts by Weight)

Compounding Ingredients	S64	S64B	N87	N87B33	M75EF	M75EFM	S227-2	I38ACE	Z47F	N117C	A11	A21D	B1FC	Z83
SBR 1500	100	100												
Paracril 18-80			100	100										
Neoprene WD					100	100								
Stereon 750							137.5							
Chlorobutyl HT 1066								100						
Hycar 4021									100					
Hycar 1072										100				
Cis Polyisoprene (IR)											100			
Pale Crepe												100		
Ameripol CB													114	
Viton B														100
Philblack A	50	50	50	50							50	50		
Statex 125					40	40	70			30				
Philblack O								60	30				60	
Thermax MT														20
Zinc Oxide	3	3	5	5	5	5	2	3		5	3	5	5	
Stearic Acid	2	2	1	1			2	1	1	2	2	1		
Neozone D	1	1					1				1	1	1	
Agerite Resin D	1	1	1	1						1	1			
Akroflex CD					3	3								
Antioxidant 2246								1						
Santocure	1	1					1.4				1		1.5	
Sulfur	1.75	1.75	1.5	1.5			1.7		0.5		1.75		1.5	
Altax			1.5	1.5				2						
Amberol ST 137X								3						
Magnesia					4	4		1						15
Diak #3														3
Methyl Tuads								1				3		
Trimene Base									3					
Tetrone A										1.5				
Captax										1.5				
Telloy												0.5		
NA-22					1	1								
U.O.P. 88		3		5			5							
Ottacide P						2								
Dioctyl sebecate					35	35								
Necton 60 Oil								5						
Heliozone	1	1		1	3	3	1							
Triethanolamine				3										
Curing Conditions	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	45 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F Step cure in air oven 1 hour each @212, 250, 300 and 350°F Post cure 24 hours @ 400°F in air oven

Table 1
(Continued)

Compounding Ingredients	Z140	Z144C	Z116CFA3	Z107	Z129	Z129G	Z60D4	Z60D4M	Z51C	Z98T	Z56C3	Z56C3T13	Z81	Z81F
Nordel 1070	100													
Hypalon 40	5	10												
EPT 3509		100												
Dynagen XP 139 (polyoxypropylene)			100											
Enjay EPM (MD460-Now 404)				100										
Genthane S					100	100								
Genthane SR							100	100						
Adiprene C									100					
Silastic 432 Base Silicone										100				
SE555U High Strength Silicone											100	100		
LS422 Fluorosilicone												1	100	100
P33 Carbon Black				60										
Kosmobile 77					35	35	25	25						
Philblack A									30					
Philblack O			45							23				
ISAF Black										8				10
Neo Novacite														
Hi Sil 303		5	3	5										
Zinc Oxide			2		0.2	0.2	0.2	0.2						
Stearic Acid				1										
Calcium Stearate	0.5													
Antioxidant 2246	50	45												
Philblack E							4	4						
Multrathane E164 (TDI dimer)										1.6	1.3	1.3	1.3	1.3
Cadox TS-50 Paste	1													
Tetrone A	3.5			7	5	5	4	4	2.5					
Di Cup R			1.4											
Di Cup 40C			1.5	.32										
Santocure														
Sulfur		12.5								2				
Amberol ST137														
Ferric oxide	5							2						
Antimony trioxide														
Ottacide P		0.5												
Heliozone			1			4								
NBC														
Polycarbodiimide (PCD)														
Curing Conditions	60 min @320°F	60 min @320°F	30 min @307°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F Post cure 24 hours @300°F in air oven	30 min @320°F Post cure 24 hours @300°F in air oven	45 min @310°F	5 min @240°F Post cure 8 hours @480°F in air oven	10 min @275°F Post cure 8 hours @375°F in air oven	10 min @275°F Post cure 8 hours @375°F in air oven	5 min @240°F Post cure 24 hours @300°F in air oven	5 min @240°F Post cure 24 hours @300°F in air oven

Table 1
(Continued)

Compounding Ingredients	U28-1	U29	U29-1	U30	U31	U17-157	U17-165	U17-226	U17-229	Z173	U56	U56-1	U56-2	U56-3
Genthane SR	100													
Elastothane 455		100	100											
Adiprene C				100										
Genthane S					100									
RIA MG-80[1]						100	100							
RIA MG 1-129[2]								100	100					
Hydrin 200										100				
Thiokol ZR625											100	100	100	100
Philblack E		30	30			50	40	40	50		30	30	30	30
Philblack O				30	35									
Philblack A	35									30				
NA-22										1.5				
Di Cup 40C	5	3			5	5			5				3	3
Stearic Acid	0.2		0.2		0.2	0.4	0.4	0.4	0.4					
Sulfur			2				0.75	0.75			2	2		
Altax			4				4	4			4	4		
Captax			2				1	1			2	2		
ZC 456 Activator			1								1	1		
Cadmium Stearate			0.5				0.50	0.50			0.5	0.5		
Di Cup R				2.5										
Polycarbodiimide (PCD)	4				4							4		4
Red Lead										5				
NBC										1				
Lanolin										2				
LD-395							0.35	0.35						
Curing Conditions	30 min @320°F	15 min @320°F	15 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	45 min @310°F	40 min @310°F	40 min @310°F	40 min @310°F	40 min @310°F

[1]Polyether urethane-urea gum synthesized at Rock Island Arsenal (Same as Gum A in Table IV, Ref. 4)
[2]Polyether urethane-urea gum synthesized at Rock Island Arsenal (Similar to Gum E in Table IV, Ref. 4)

Table 1
(Continued)

Compounding Ingredients	U34	U35	U35-1	U35-2	U35-3	U35-4	U35-5	U42	U43	U43-1	U43-2	U44	U45	T192A	T355D	T480A
Witco MD2 Polyester Urethane	100															
Genthane SR w/Manufacturers Fungicide A		100	100	100												
Genthane SR w/Manufacturers Fungicide B					100	100	100	100					100			
Cyanaprene D5													35			
Genthane S																
Philblack A	5	35	35	35	35	35	35									
Cadmium Stearate	0.5												0.2			
ID 395	1												5			
Altax	4															
Captax	2												4			
Sulfur	3.5							9.5								
Stearic acid		0.2	0.2	0.2	0.2	0.2	0.2									
DI Cup 40 C		5	5	5	5	5	5									
Polycarbodiimide (PCD)			4			4										
Moltrathane E164 (TDI dimer)				4			4									
Cyanaset M																
Curing Conditions	15 min @293°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	30 min @320°F	45 min @212°F Post cure 2 weeks @ room temp.	Based on Texin 355D Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin 480A Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin 480A with "Hydrolysis Stabilizer" added. Received as Molded Test Pads. Formulation Unknown.	Based on Niax D540 Caprolactone Urethane. Received as Molded Test Pads. Formulation Unknown.	30 min @320°F	Based on Texin 192A Polyester Urethane. Injection Molded at Rock Island Arsenal. Formulation Unknown.	Based on Texin 355D Polyester Urethane. Injection Molded at Rock Island Arsenal. Formulation Unknown.	Based on Texin 480A Polyester Urethane. Injection Molded at Rock Island Arsenal. Formulation Unknown.

Table 1
(Continued)

Compounding Ingredients	Z113	E20	A11A1C2	N87D4C2	S77D10C2	S211	S206-5	S209-1	S209-2	U75-1	B33-4	S223-4	Z180	Z180-2
Nordel 1070	100		30	30	30									
Royalene 306		100												
Pale Crepe			70											
SBR 1500					70	100	80	70	70					
Paracril 18-80				70										
EP syn 55								30						
Vistalon 6505									30					
Royalene 400							40							
Adiprene CM										100				
HYTRANS 1227-176-2[3]											137.5			
HYTRANS 1227-176-1[4]												137.5		
Hydrin 100													100	
Hydrin 200														100
Philblack A	60												30	30
Philblack O		50			50					30				
Philblack E			50	50										
Statex 160						45	45	45	45		70	70		
Stearic acid	1	1	2	1	2	2	2	2	2		2	2		
Zinc Oxide	5	5	3	5	3	3	3	3	3		4	4		
Neozone D			1		1	1	1	1	1		1	1		
Sulfur	0.5	1.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.75	2	2		
Monex	1													
Captax	1.5	0.5								1				
Thionex		1.5												
Di Cup 40C			5	2.5	5	5	5	5	5					
Santocure			0.5	0.5	0.5	0.5	0.5	0.5	0.5		1.5	1.5		
Cumar W 2½										10				
Altax										4				
NA-22														
Necton 60 Oil		20											1	1.5
Process Oil	10													
Caytur 4														
Cadmium Stearate										0.35				
Dyphos										0.5				
Red Lead													5	
U.O.P. 88														5
Heliozone											5	5		
											1	1		
Curing Conditions	30 min @320°F	30 min @320°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	30 min @307°F	60 min @287°F	45 min @310°F	45 min @310°F	45 min @310°F	45 min @310°F

[3] HYTRANS 1227-176-2 (Alfin catalyzed copolymer of 90/10 Butadiene/Isoprene - 37.5 parts oil extended)
[4] HYTRANS 1227-176-1 (Alfin catalyzed copolymer of 85/15 Butadiene/Styrene - 37.5 parts oil extended)

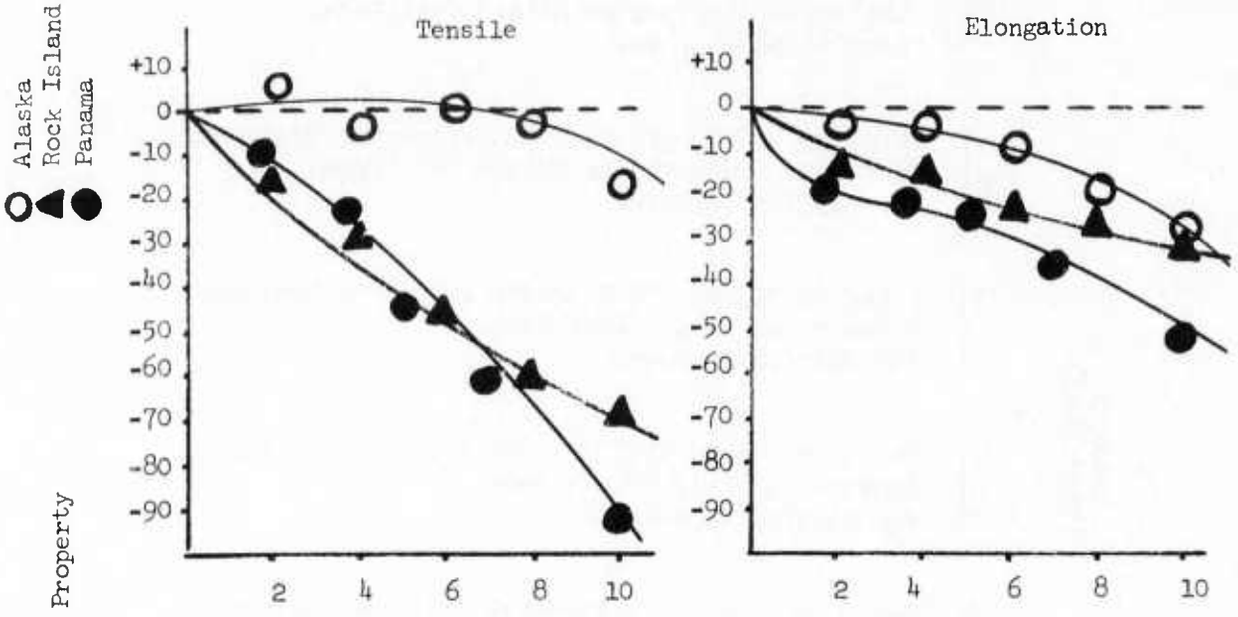
Table 1
(Continued)

Compounding Ingredients	G44	S202	S202-1	58300	58304	58013	U57	U57-1	U57-2	U79	U79-1	U79-2	U79-3	U79-4
746U Silicone	100													
SBR 1500		70												
Stereon 720			70											
Nordel 1470		30												
Nordel 1440			30											
Statex 160		45	45											
Di Cup 40C	0.55	5	5											
Zinc Oxide		3	3											
Stearic acid		2	2											
Santocure		0.5	0.5											
Sulfur		0.2	0.2											
Neozone D		1	1											
Curing Conditions	10 min @300°F	30 min @307°F	30 min @307°F	Based on Estane 58300 Urethane of Unknown Type. Received as Molded Test Pads. Formulation Unknown.	Based on Estane 58304 Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Estane 58013 Urethane of Unknown type. Received as Molded Test Pads. Formulation Unknown.	Based on Upjohn X29-83 (2092-60D) Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Upjohn CPR 2092-90A Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Upjohn X29-77 A (2094-90A) Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin 591A Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin XP275 Polyester Urethane. Reeeived as Molded Test Pads. Formulation Unknown.	Based on Texin 355DXH Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin XPE-290 Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.	Based on Texin XPE-290 Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.

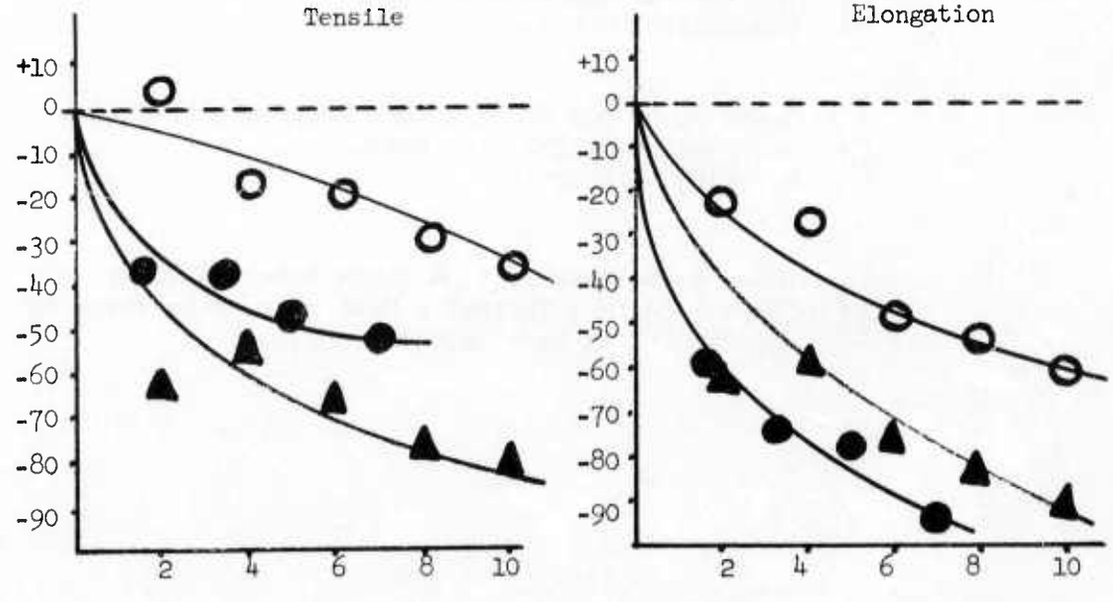
Table 1
(Continued)

U83-6	Based on Upjohn CPR 2353-55D Polyester/Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.
U83-5	Based on Upjohn CFR 2353-80A Polyester/Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.
U83-4	Based on Upjohn CPR 2103-55D Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.
U83-3	Based on Upjohn CPR 2103-80A Polyether Urethane. Received as Molded Test Pads. Formulation Unknown.
U83-2	Based on Upjohn CPR 2102-55D Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.
U83-1	Based on Upjohn CPR 2102-90A Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.
U83	Based on Upjohn CPR 2102-80A Polyester Urethane. Received as Molded Test Pads. Formulation Unknown.
U65	Based on Vibrathane 5004 Stock Received Fully Compounded from Thiokol - Test pads press cured 45 min. @310°F at Rock Island Arsenal.

A21D Cis Polyisoprene



B1FC Ameripol CB (Cis Polybutadiene)



Percent Change from Original (Unaged) Property

Aging Time, Years (Open Sun)

Figure 1

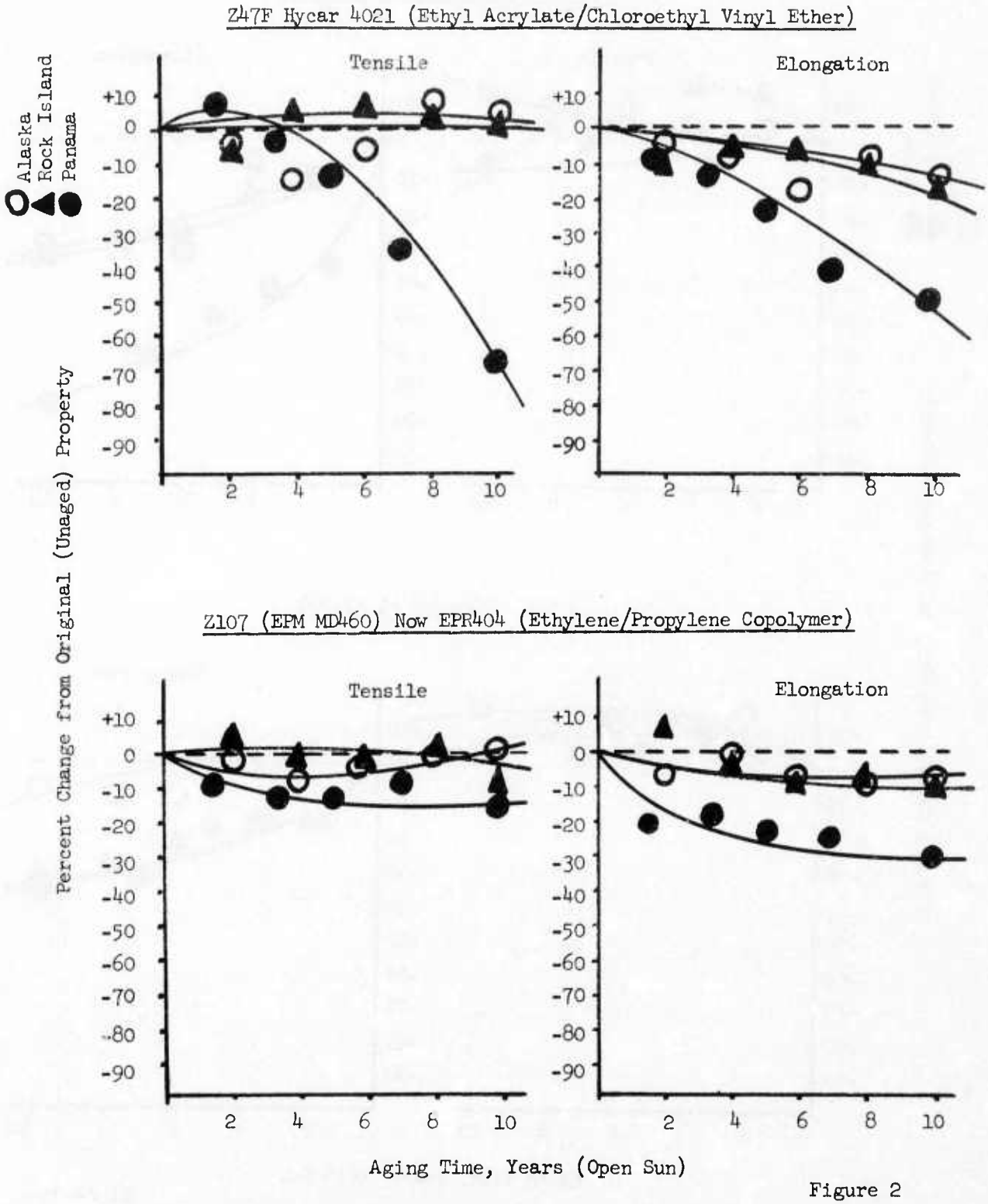
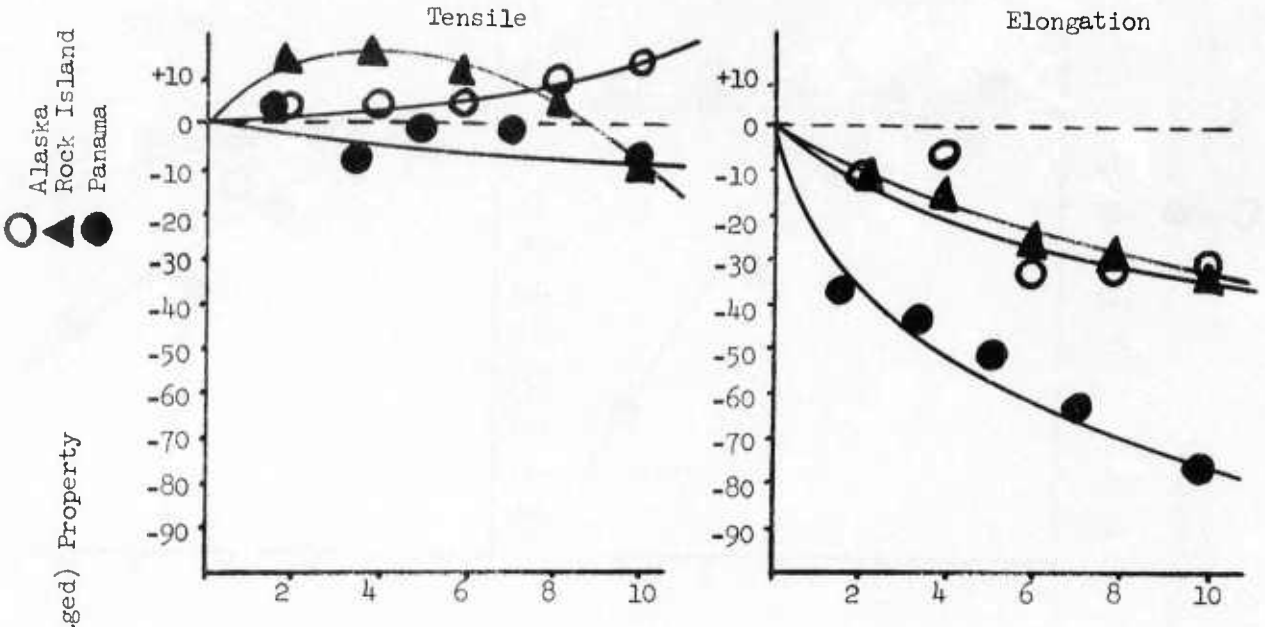
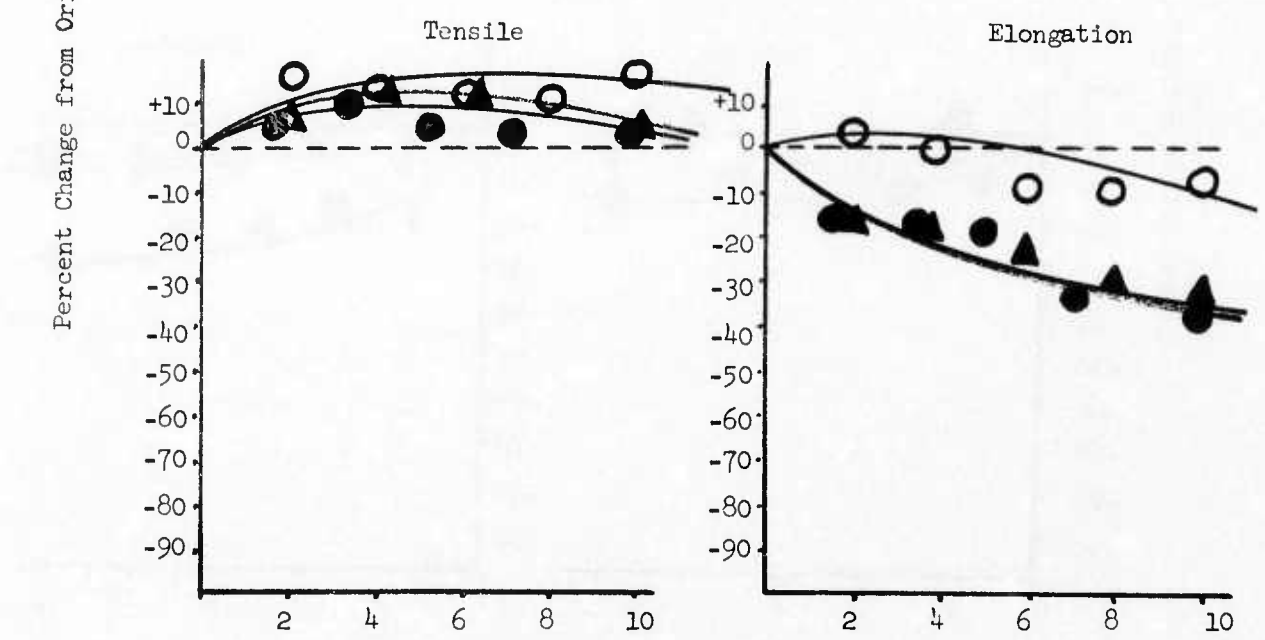

Z47F Hycar 4021 (Ethyl Acrylate/Chloroethyl Vinyl Ether)
Tensile
Elongation
Alaska
Rock Island
Panama
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
Z107 (EPM MD460) Now EPR404 (Ethylene/Propylene Copolymer)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years (Open Sun)

Figure 2

N117C Hycar 1072 (Carboxylic)



I38ACE Chlorobutyl HT1066



Percent Change from Original (Unaged) Property

Aging Time, Years (Open Sun)

Figure 3

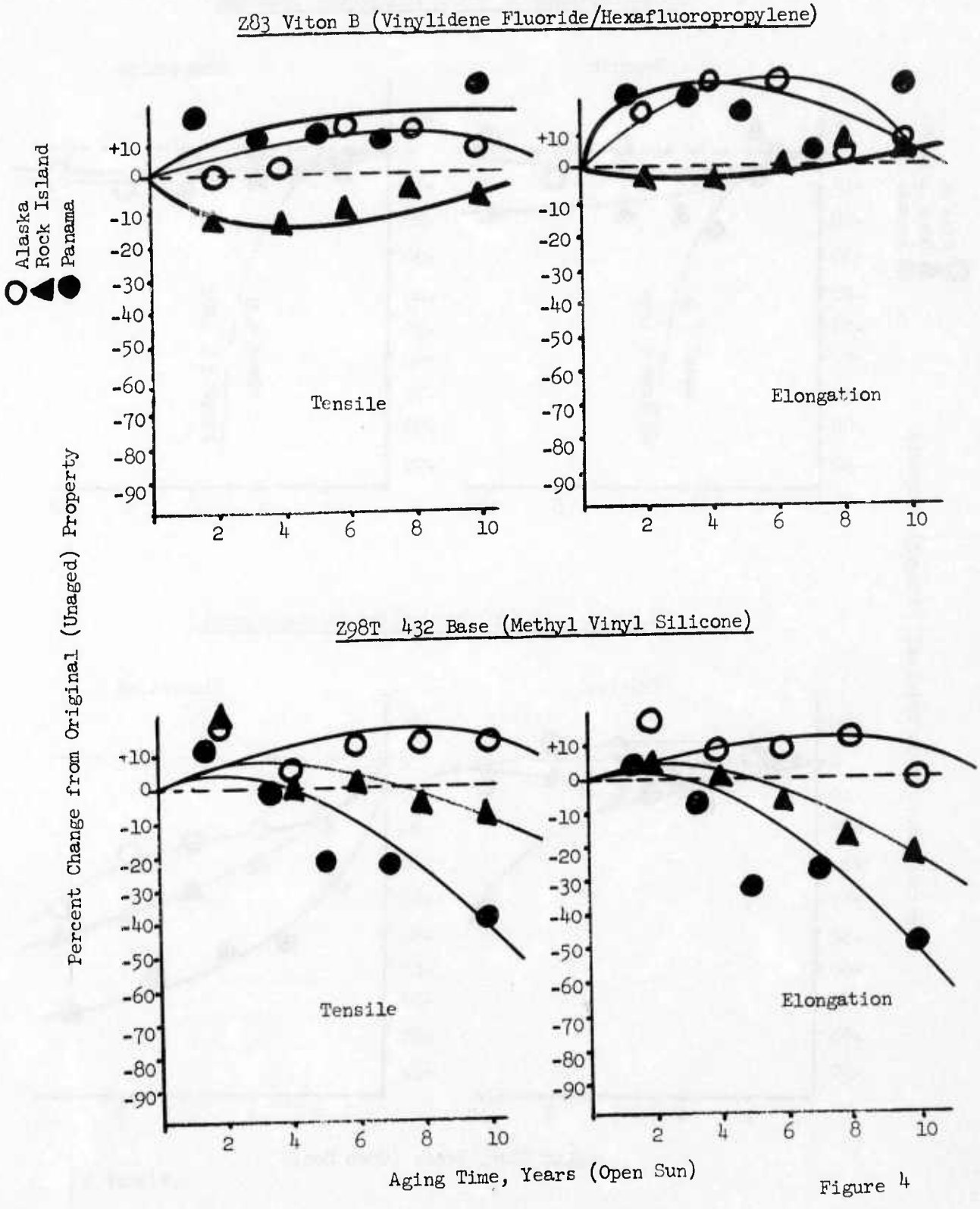

Z83 Viton B (Vinylidene Fluoride/Hexafluoropropylene)
Alaska
Rock Island
Panama
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Tensile
Elongation
2
4
6
8
10
Z98T 432 Base (Methyl Vinyl Silicone)
Tensile
Elongation
Aging Time, Years (Open Sun)

Figure 4

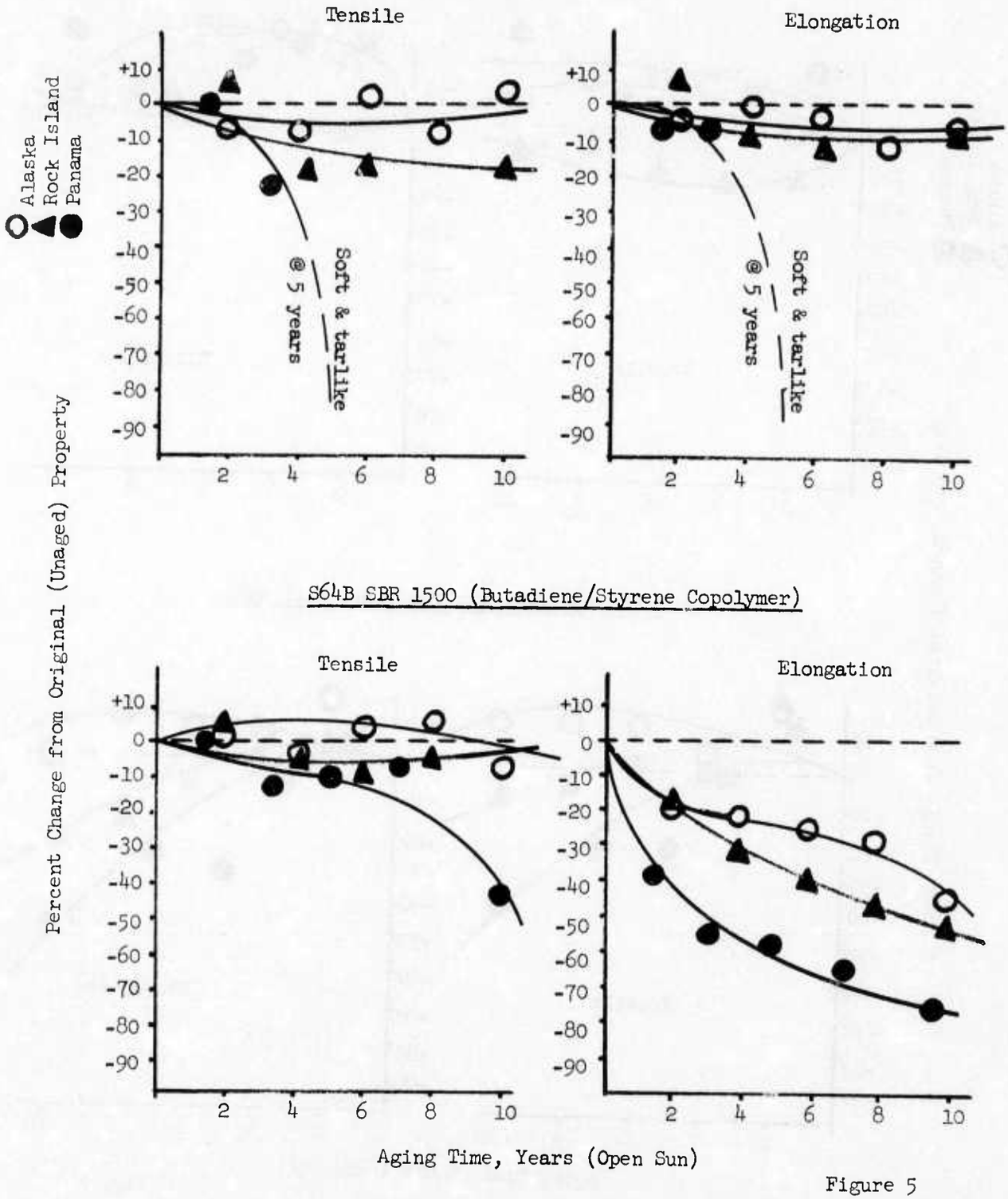

Z60D4 Genthane SR w/TDI (Polyester Urethane)
Tensile
Elongation
Alaska
Rock Island
Panama
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
Soft & tarlike @ 5 years
S64B SBR 1500 (Butadiene/Styrene Copolymer)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years (Open Sun)

Figure 5

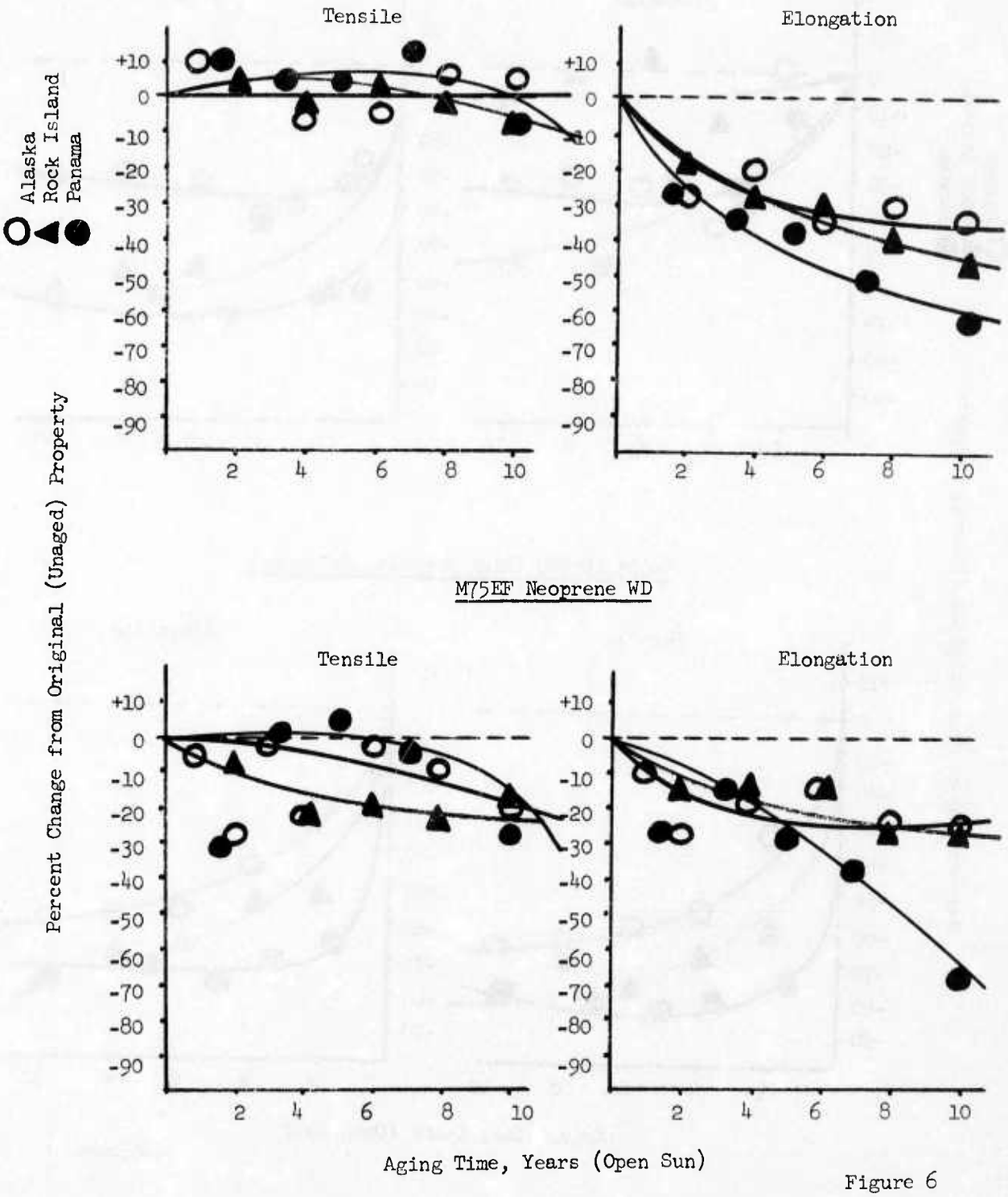
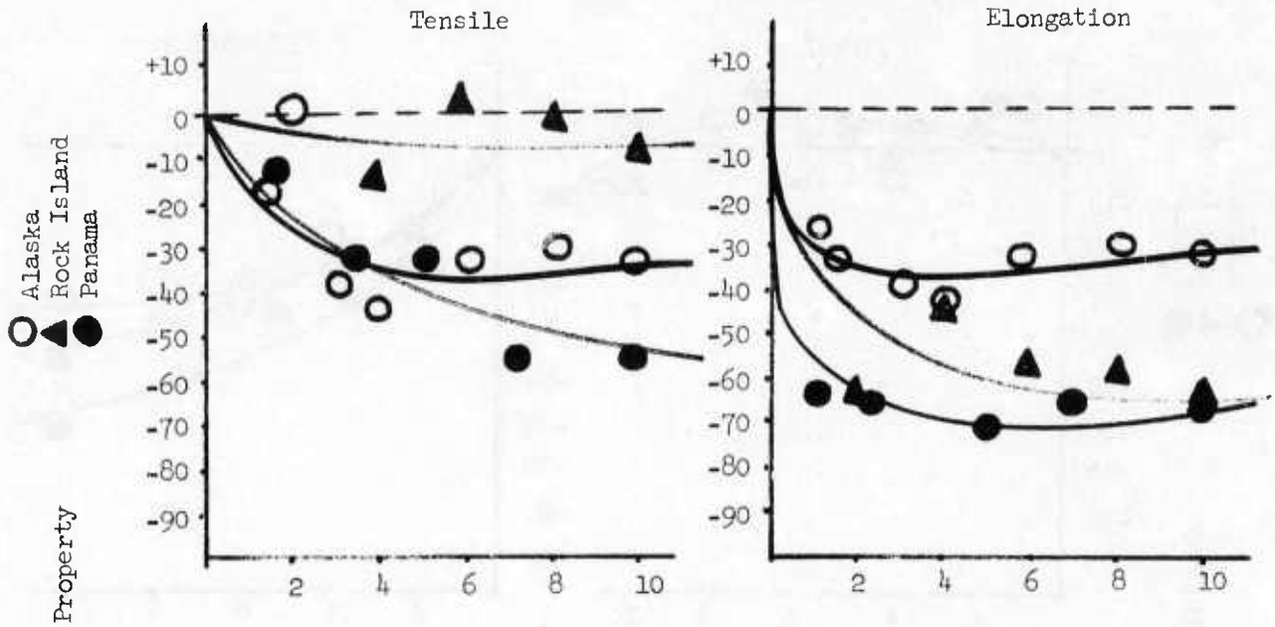
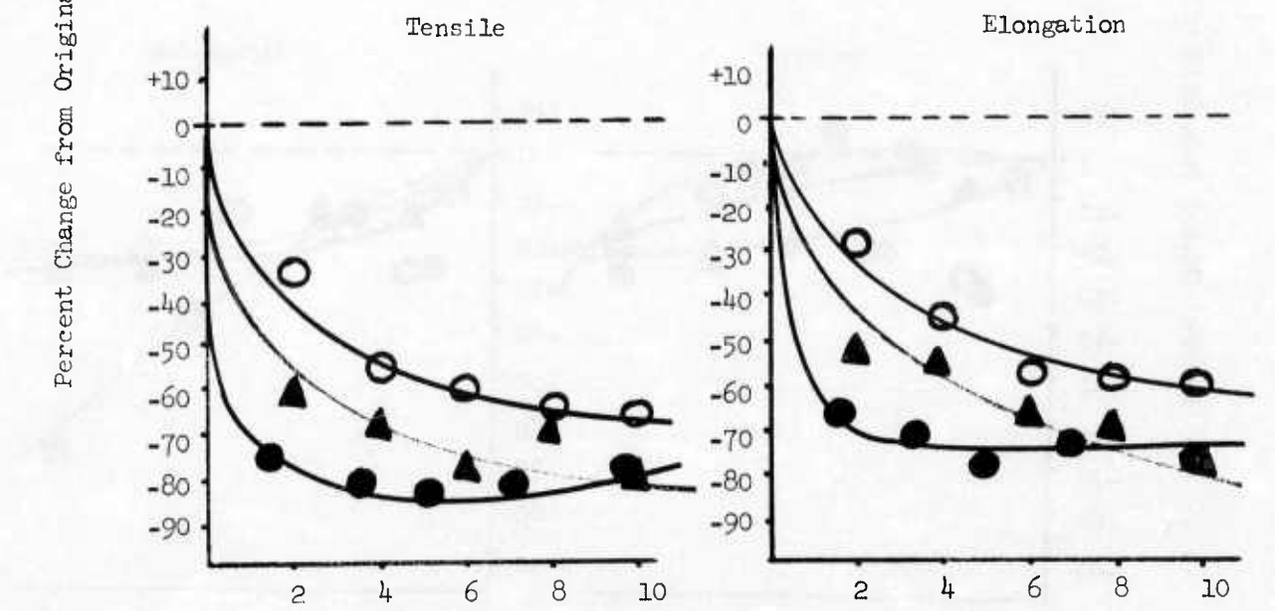

N87B33 Paracril 18-80 (Butadiene/Acrylonitrile Copolymer)
Tensile
Elongation
Alaska
Rock Island
Panama
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
M75EF Neoprene WD
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years (Open Sun)

Figure 6

Z81F 422 Base (Fluorosilicone)



Z56C3 SE555U (High Strength Silicone)



Percent Change from Original (Unaged) Property

Aging Time, Years (Open Sun)

Figure 7

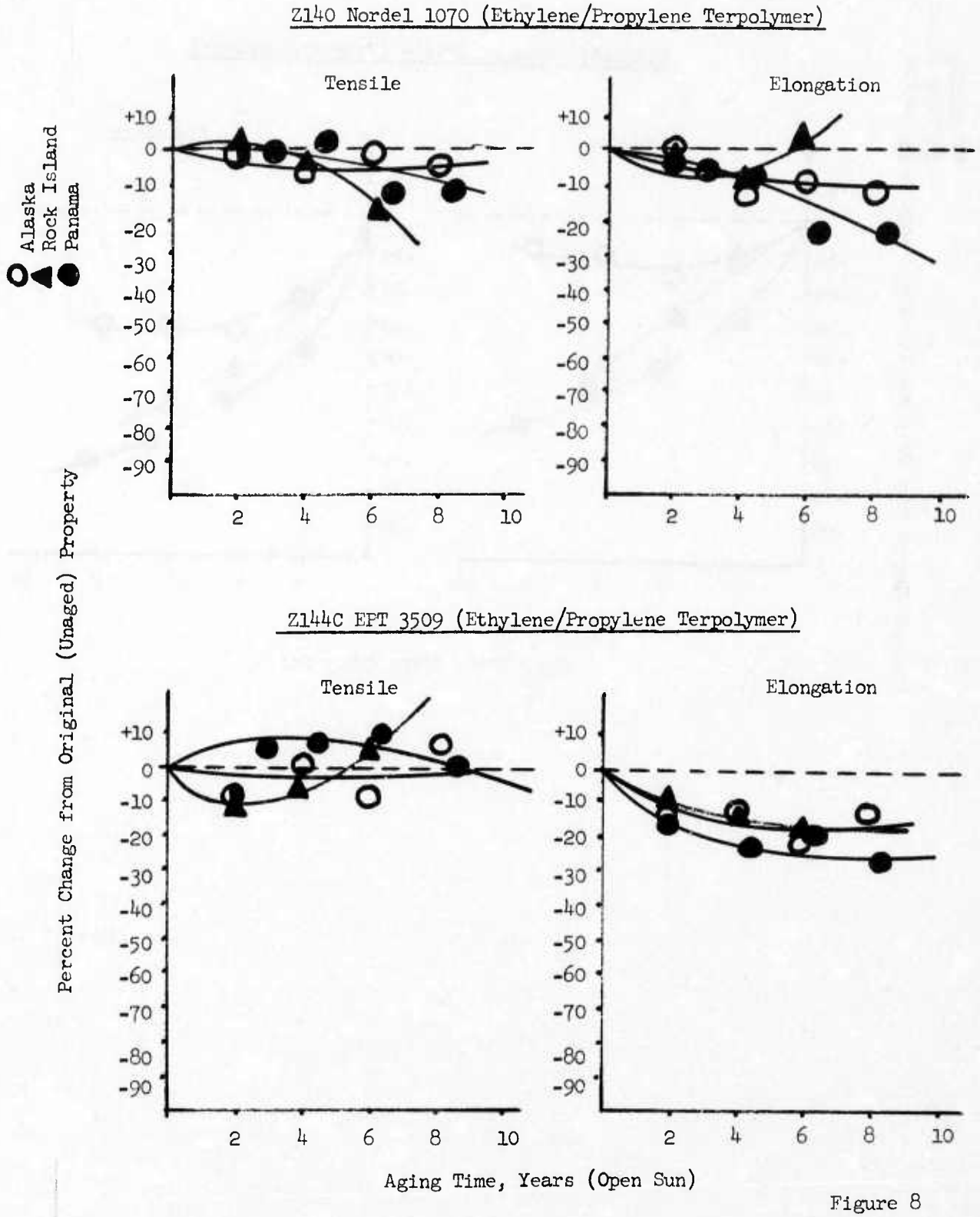

Z140 Nordel 1070 (Ethylene/Propylene Terpolymer)
Tensile
Elongation
Alaska
Rock Island
Panama
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
Z144C EPT 3509 (Ethylene/Propylene Terpolymer)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years (Open Sun)

Figure 8

Z116CFA3 Dynagen XP-139 (Polyoxypropylene)

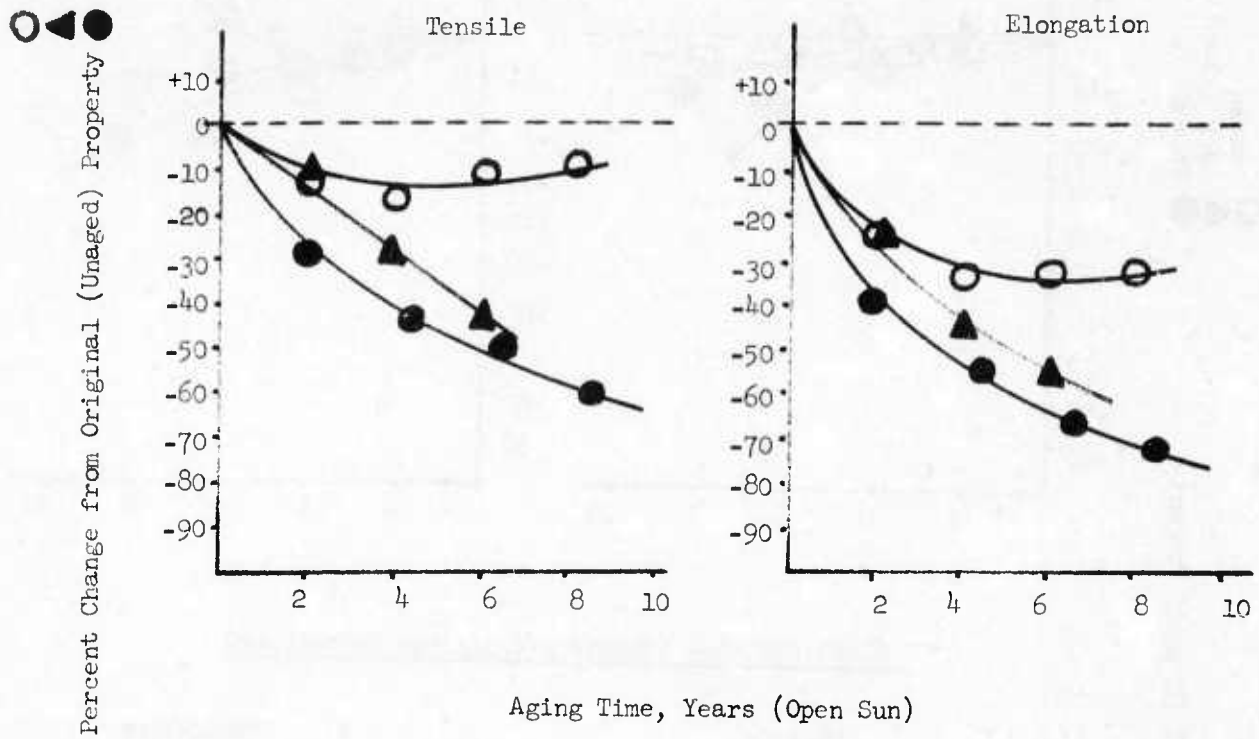


Figure 9

Accelerated air oven aging tests were run on selected vulcanizates at temperatures of either 212°F or 400°F, depending upon the heat resistance of the vulcanizate, so that a comparison could be made between accelerated and outdoor aging for correlation purposes. Graphs in which the accelerated air oven aging test results are illustrated are shown in Figures 10 through 12. The following statement was made in a previous report[4] by this Arsenal:

> "It is the opinion of this Arsenal, after evaluating numerous aging test programs, that efforts to directly correlate accelerated aging tests with indoor and outdoor aging tests is a futile and unrewarding task. Accelerated aging tests are helpful in giving indications of the aging resistance of rubber vulcanizates but are not accurate in predicting the actual performance life which may be expected of the vulcanizate."

It was also stated in this report that:

> "It was found that an aging test conducted in an air oven at 158°F was not much of an "accelerated" aging test. This is not surprising since a recent study (RIA Laboratory Report No. 60-2561, 31 Aug 1960) conducted at this Arsenal has shown that temperatures as high as 140°F were reached on the surface of the rubber specimens exposed outdoors in direct sunlight during the hot summer months. A temperature higher than 158°F should, therefore, be used in accelerated air oven-aging tests. A temperature of 212°F is sometimes used, and it is the opinion of this Arsenal that this temperature is more realistic for an accelerated air oven aging test."

Personnel of this Arsenal still regard the above-cited opinions as being valid today. For this reason, the accelerated vs. outdoor aging test results were closely examined to determine if the accelerated tests accurately indicated the aging resistance which could be expected from the same vulcanizates exposed outdoors. These results are given in Tables 2 through 4. In most instances, the results of the accelerated aging tests, in very general terms, gave a good indication of how the vulcanizates would resist outdoor aging; especially when elongation values are compared. One notable exception to this generalization, as would be expected, is the polyester urethane vulcanizate (Z60D4). Accelerated tests indicate that this elastomer should be more age-resistant than many of the other vulcanizates in outdoor tests; but, because of its susceptibility to hydrolytic decomposition, it exhibits the poorest resistance to aging in Panama (high humidity), while resisting aging very well in Alaska and at Rock Island. Air oven aging tests (ASTM D573-67) are not meant to indicate susceptibility to hydrolytic decomposition, which is usually assessed by ASTM Method D3137-72T. The susceptibility of compound Z47F to hydrolytic attack also explains why it suffers much greater loss in tensile strength in Panama than would be expected from the accelerated test results. Accelerated tests using elongation as the criterion for

[4]Bergstrom, E.W., "Indoor and Outdoor Aging of Elastomeric Vulcanizates over a Ten Year Period", Technical Report 61-3868, AD 271 190, October 1961.

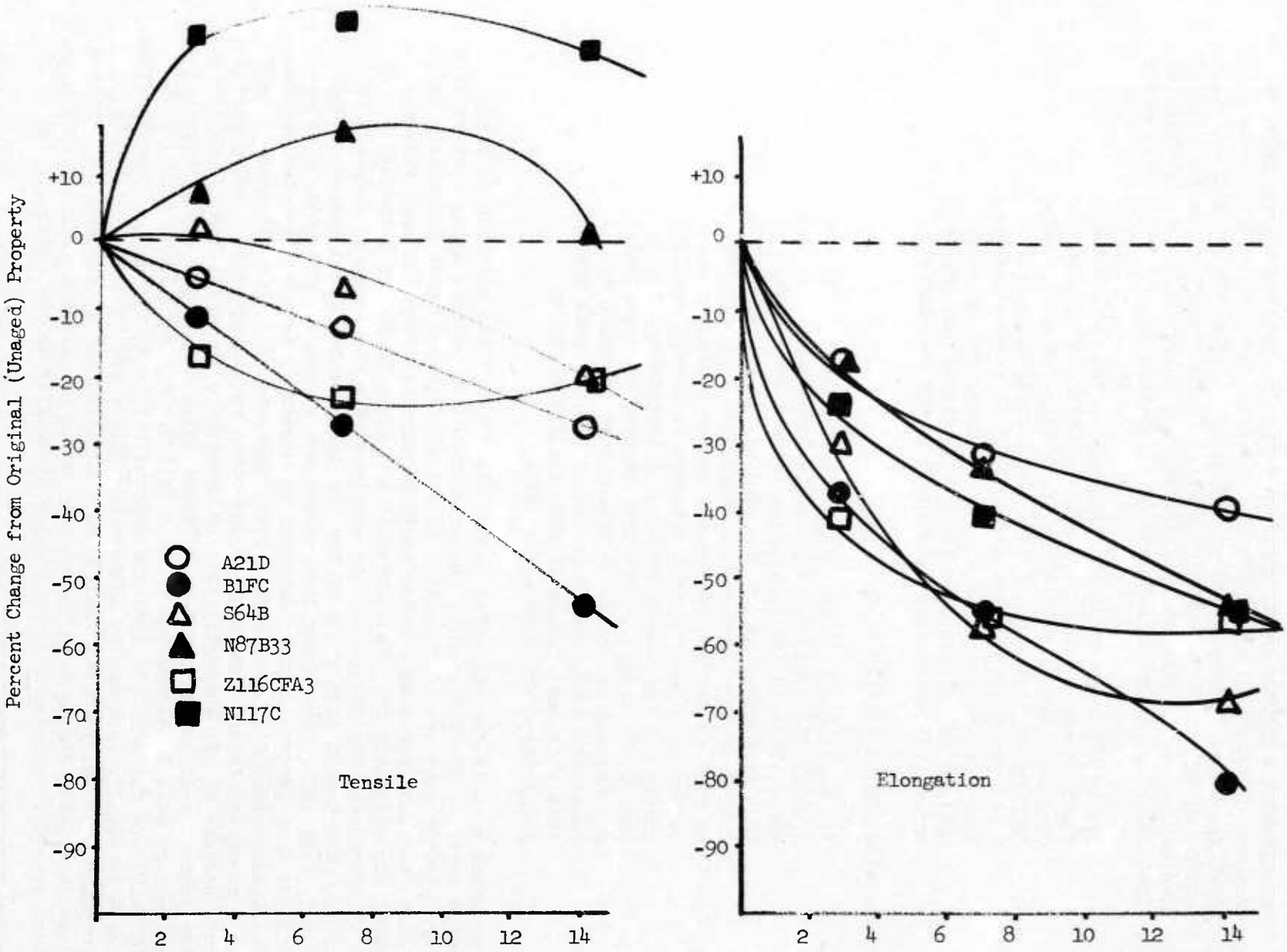

Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
A21D
B1FC
S64B
N87B33
Z116CFA3
N117C
Tensile
Elongation
2
4
6
8
10
12
14
Aging Time, Days @212°F (Air Oven)

Figure 10

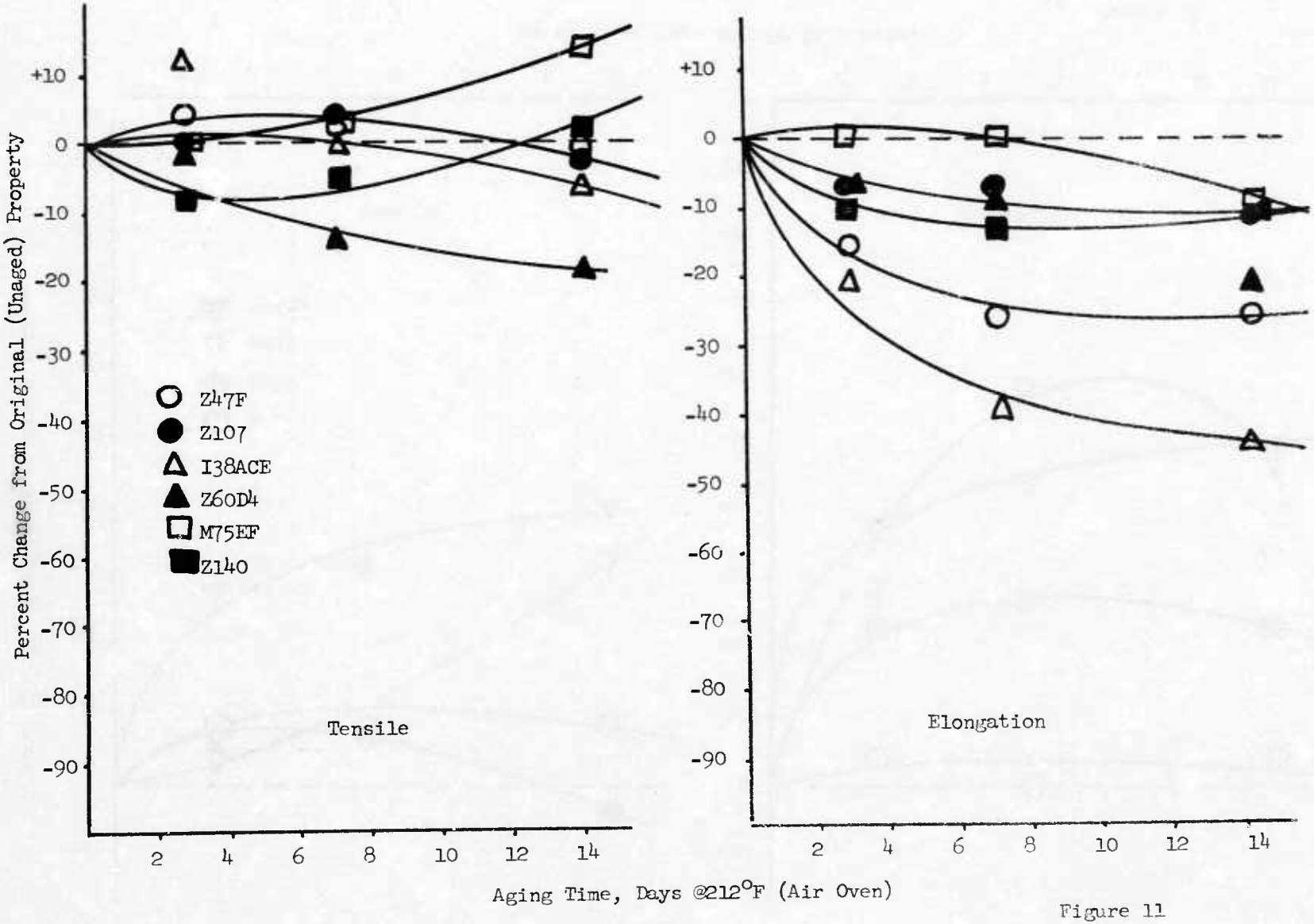

+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Percent Change from Original (Unaged) Property
Z47F
Z107
I38ACE
Z60D4
M75EF
Z140
Tensile
Elongation
2
4
6
8
10
12
14
Aging Time, Days @212°F (Air Oven)

Figure 11

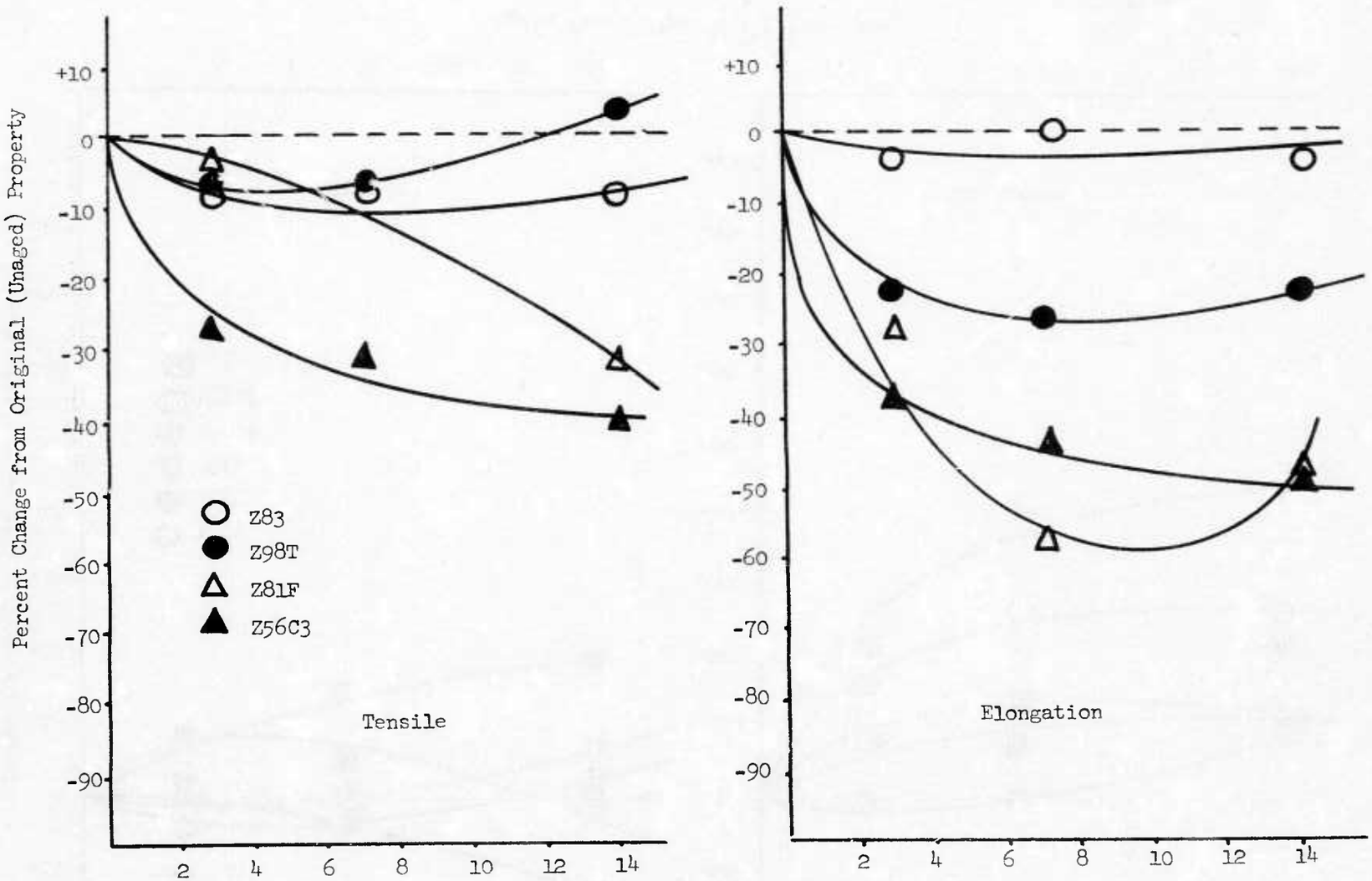

Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
12
14
Z83
Z98T
Z81F
Z56C3
Tensile
Elongation
Aging Time, Days @400°F (Air Oven)

Figure 12

Table 2
ACCELERATED VS. OUTDOOR AGING RESISTANCE

Tensile Strength

Air Oven Aged 14 Days @ 212°F		Outdoor Aging 10 Years: Alaska		Rock Island		Panama	
N117C	(+29)*	I38ACE	(+17)	I38ACE	(+ 4)	I38ACE	(+ 3)
M75EF	(+14)	N117C	(+13)	Z47F	(0)	N87B33	(- 7)
Z140	(+ 2)	N87B33	(+ 5)	N87B33	(- 7)	N117C	(- 8)
N87B33	(+ 1)	Z47F	(+ 4)	S64B	(- 8)	Z140	(-11)
Z47F	(- 1)	Z60D4	(+ 3)	N117C	(-10)	Z107	(-15)
Z107	(- 2)	Z107	(+ 1)	Z107	(-10)	M75EF	(-36)
I38ACE	(- 6)	Z140	(- 3)	Z140	(-17)	S64B	(-43)
Z60D4	(-19)	S64B	(- 8)	Z60D4	(-18)	Z116CFA3	(-60)
S64B	(-20)	Z116CFA3	(- 9)	M75EF	(-18)	Z47F	(-69)
Z116CFA3	(-20)	M75EF	(-18)	Z116CFA3	(-42)	A21D	(-92)
A21D	(-27)	A21D	(-19)	A21D	(-69)	B1FC	(Brittle after 8 years)
B1FC	(-54)	B1FC	(-35)	B1FC	(-80)	Z60D4	(Soft & tarlike after 5 years)

*Values in parentheses are percent change from original (unaged) values

Table 3
ACCELERATED VS. OUTDOOR AGING RESISTANCE

Air Oven Aged 14 Days @212°F		Elongation Outdoor Aging 10 Years Alaska		Rock Island		Panama	
M75EF	(- 9)*	Z60D4	(- 6)	Z140	(+ 5)	Z140	(-23)
Z140	(-10)	Z107	(- 7)	Z60D4	(- 9)	Z107	(-30)
Z107	(-11)	I38ACE	(- 8)	Z107	(-11)	I38ACE	(-39)
Z60D4	(-21)	Z140	(-11)	Z47F	(-19)	Z47F	(-50)
Z47F	(-26)	Z47F	(-14)	M75EF	(-26)	A21D	(-51)
A21D	(-39)	M75EF	(-22)	A21D	(-31)	N87B33	(-63)
I38ACE	(-44)	A21D	(-28)	I38ACE	(-32)	M75EF	(-66)
N87B33	(-53)	Z116CFA3	(-33)	N117C	(-34)	Z116CFA3	(-72)
N117C	(-54)	N117C	(-33)	N87B33	(-47)	S64B	(-75)
Z116CFA3	(-55)	N87B33	(-33)	S64B	(-52)	N117C	(-78)
S64B	(-68)	S64B	(-45)	Z116CFA3	(-55)	B1FC	(Brittle after 8 years)
B1FC	(-80)	B1FC	(-60)	B1FC	(-90)	Z60D4	(Soft & tarlike after 5 years)

*Values in parentheses are percent change from original (unaged) values

Table 4
ACCELERATED VS. OUTDOOR AGING RESISTANCE

Tensile Strength

Air Oven Aged 14 Days @400°F	Outdoor Aging 10 Years		
	Alaska	Rock Island	Panama
Z98T (+ 3)*	Z98T (+14)	Z83 (- 7)	Z83 (+27)
Z83 (- 8)	Z83 (+ 8)	Z81F (- 9)	Z98T (-39)
Z81F (-32)	Z81F (-32)	Z98T (-10)	Z81F (-55)
Z56C3 (-40)	Z56C3 (-65)	Z56C3 (-80)	Z56C3 (-79)

Elongation

Air Oven Aged 14 Days @400°F	Outdoor Aging 10 Years		
	Alaska	Rock Island	Panama
Z83 (- 4)	Z83 (+ 8)	Z83 (+ 4)	Z83 (+25)
Z98T (-22)	Z98T (0)	Z98T (-24)	Z98T (-48)
Z81F (-46)	Z81F (-39)	Z81F (-62)	Z81F (-67)
Z56C3 (-48)	Z56C3 (-59)	Z56C3 (-78)	Z56C3 (-76)

*Values in parentheses are percent change from original (unaged) values

measuring age resistance predicted the superior aging resistance during outdoor aging of the ethylene/propylene copolymer (Z107) and terpolymer (Z140) vulcanizates, for example, when compared with butadiene/acrylonitrile, butadiene/styrene, cis polybutadiene and polyoxypropylene vulcanizates. This fact substantiates the opinion that accelerated aging tests do have some degree of validity in the prediction of differences in outdoor age resistance. Also, the accelerated aging tests conducted at 400°F predicted exactly the outdoor aging characteristics of the four vulcanizates examined when elongation was used as the criterion for measuring aging resistance. Results were given previously[1,2] on the pronounced loss in tensile strength of a high strength silicone vulcanizate; this was attributable to ultraviolet attack. The data in Figure 13 confirm the effectiveness of one part P33 carbon black in significantly improving the outdoor aging resistance of this vulcanizate.

Results are also available on test pads exposed at a tropical rain forest site in Panama and in a hut next to the rain forest for comparison with open sun exposure tests. The results are shown graphically in Figures 14 through 19. Certain vulcanizates, namely those based on Nordel 1070, Chlorobutyl HT 1066, Viton B, 432 Base silicone and Adiprene C, exhibited good aging resistance at all three test sites.

A comparison was made of properties determined on pads aged indoors vs. outdoors for ten years at Rock Island Arsenal. These results are shown graphically in Figures 20 through 26. In general, certain vulcanizates such as cis polyisoprene, cis polybutadiene, and SE555U high strength silicone, have significantly better age resistance indoors than outdoors, while other vulcanizates such as Hycar 4021, EPR 404, Hycar 1072, and Chlorobutyl HT 1066, for example, exhibit almost identical age resistance indoors and outdoors. The pads aged indoors at Rock Island, Illinois, were separated by polyethylene film and stored in drawers in the laboratory at ambient temperature ranging from 70°F to 95°F.

As was stated in the previous report[2] on this subject, the most dramatic effect of climatic aging on rubber vulcanizates has been found with the polyester urethane vulcanizates which deteriorate very rapidly when aged outdoors in humid climates. An investigation[5] made at this installation has shown that, at temperatures of 120°F and above, deterioration is due to hydrolysis of the main chain ester group, resulting in reversion. Deterioration at temperatures below 120°F was found to be more complex, involving both a rapid hydrolytic cracking of stressed or unstressed specimens and a gradual reversion over a period of many months. The cracking appears to result from microbiological attack. The hydrolytic decomposition of polyester urethanes can be retarded by the use of additives such as diisocyanates (TDI dimer) and carbodiimides (PCD); however, the problem is considered to be only partially solved. The results of outdoor aging in Panama on various polyurethane vulcanizates previously reported[2] and those polyurethane vulcanizates placed in exposure since issuance of that report are given in Table 5. The rapid deterioration of polyester urethanes, even those containing hydrolysis inhibitors, is very evident, and, although it was originally thought that polyether urethanes were virtually unaffected by outdoor exposure in Panama, results now indicate that significant deterioration (see compound U30) occurs in the rain forest.

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[1] Bergstrom, E.W., Ibid

[2] Bergstrom, E.W., Ibid

[5] Ossefort, Z.T. and Testroet, F.B., "Hydrolytic Stability of Urethan Elastomers", Rubber Chemistry & Technology, Vol. 39, No. 4, Part 2, pp. 1308-1327, Sept. 1966

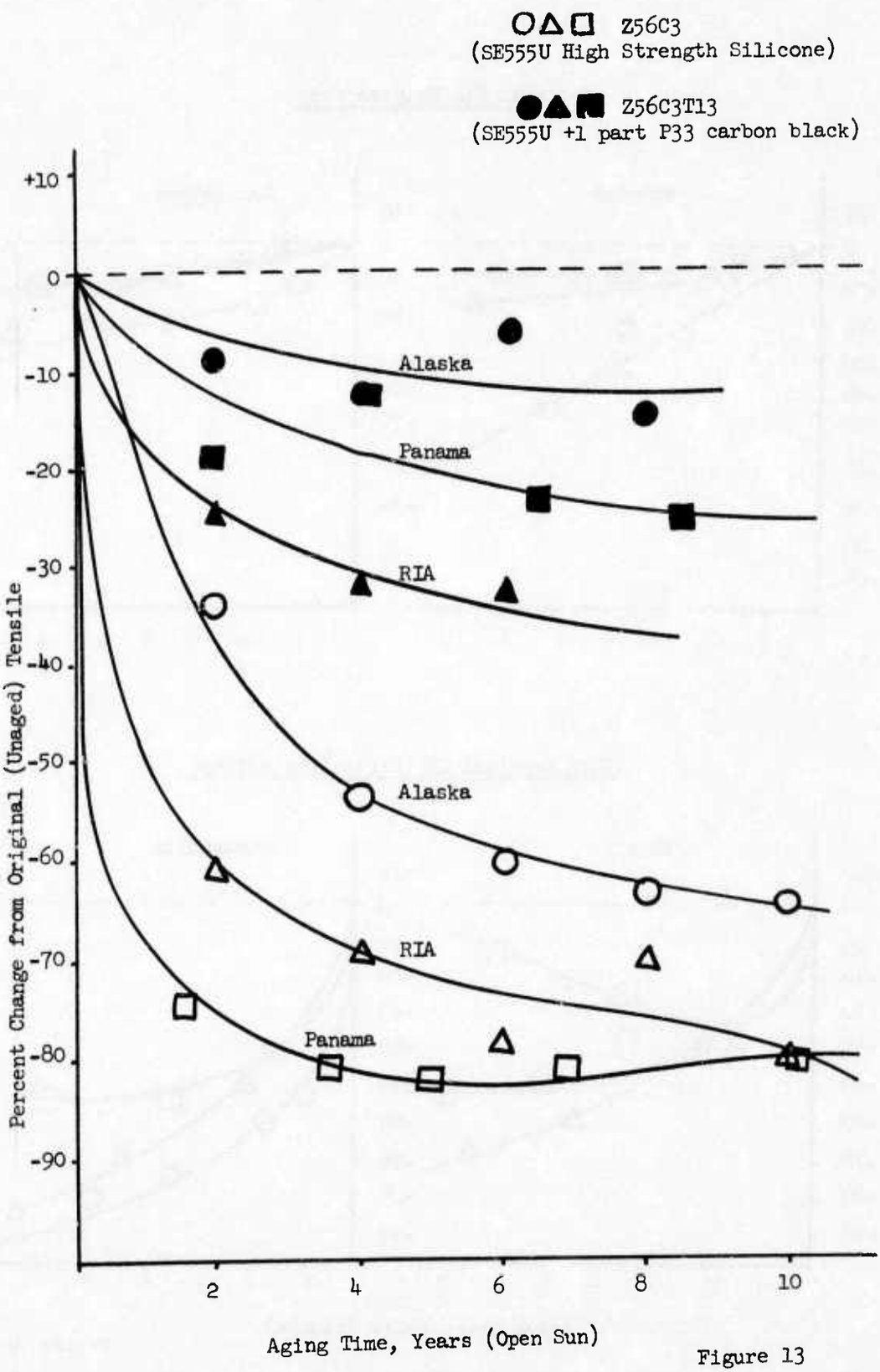

○△□ Z56C3
(SE555U High Strength Silicone)
●▲■ Z56C3T13
(SE555U +1 part P33 carbon black)
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Alaska
Panama
RIA
Alaska
RIA
Panama
Percent Change from Original (Unaged) Tensile
2
4
6
8
10
Aging Time, Years (Open Sun)

Figure 13

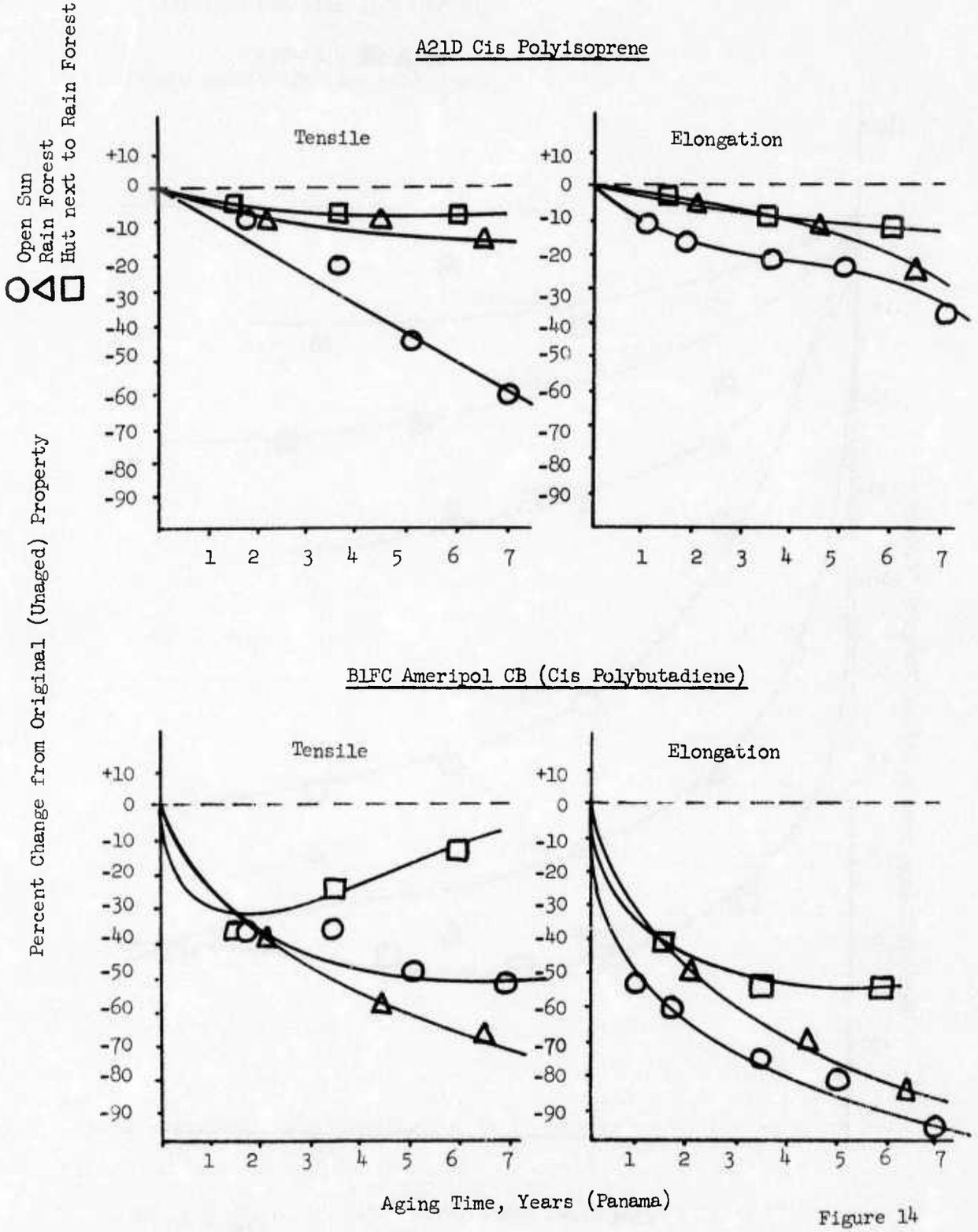

A21D Cis Polyisoprene
Tensile
Elongation
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1 2 3 4 5 6 7
B1FC Ameripol CB (Cis Polybutadiene)
Tensile
Elongation
Aging Time, Years (Panama)

Figure 14

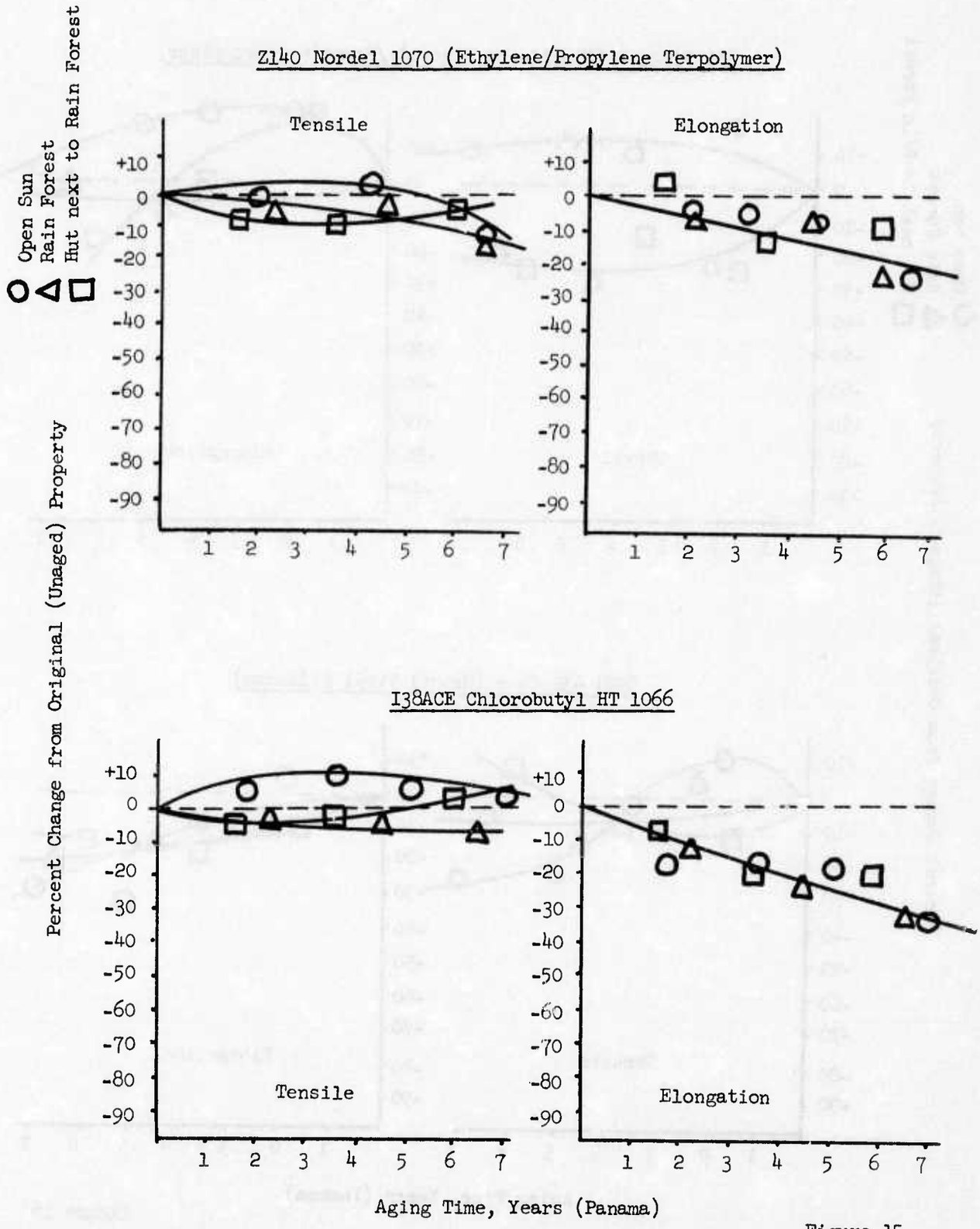

Z140 Nordel 1070 (Ethylene/Propylene Terpolymer)
Tensile
Elongation
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1 2 3 4 5 6 7
I38ACE Chlorobutyl HT 1066
Tensile
Elongation
Aging Time, Years (Panama)

Figure 15

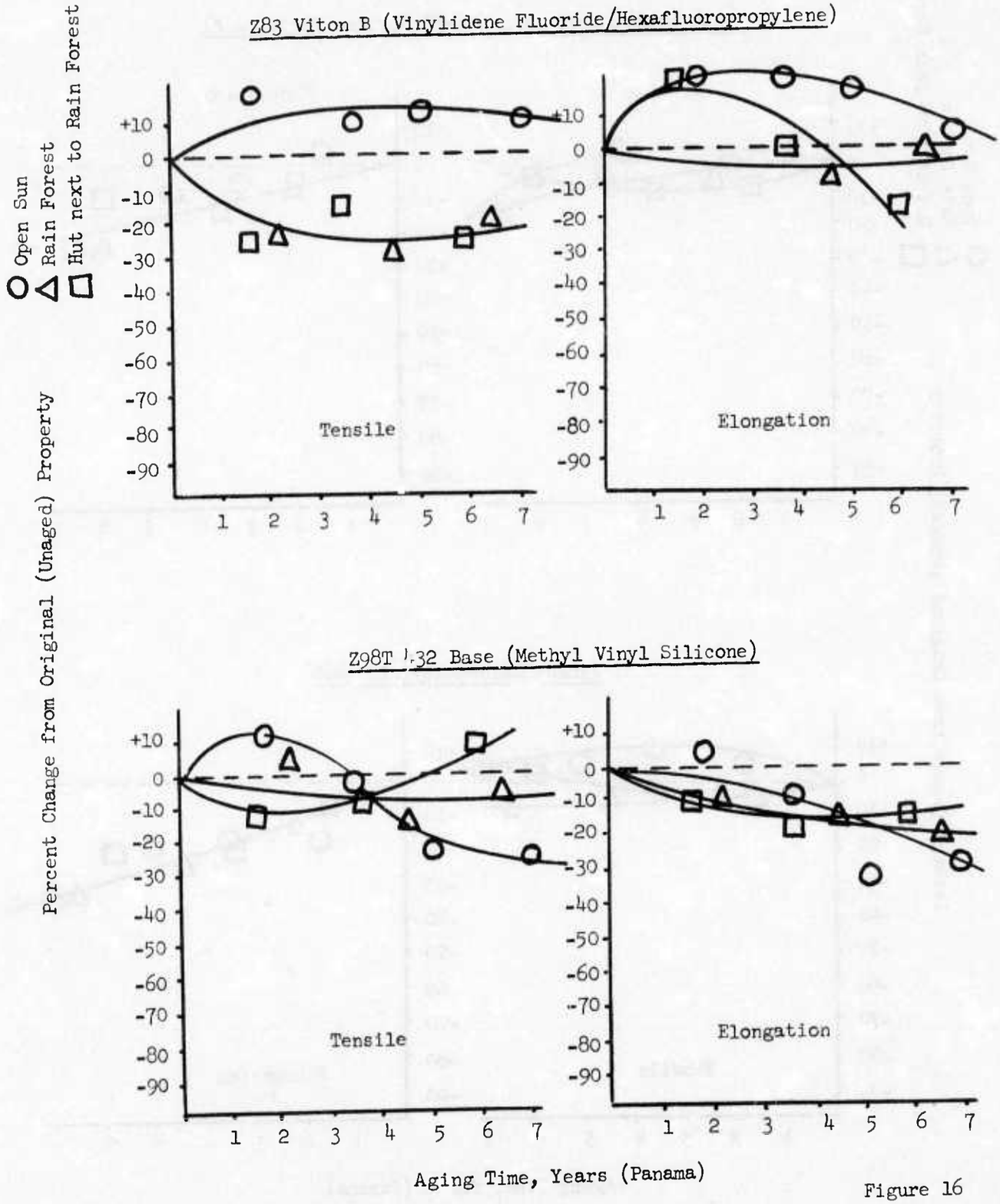

Z83 Viton B (Vinylidene Fluoride/Hexafluoropropylene)
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Tensile
Elongation
1 2 3 4 5 6 7
Z98T 132 Base (Methyl Vinyl Silicone)
Aging Time, Years (Panama)

Figure 16

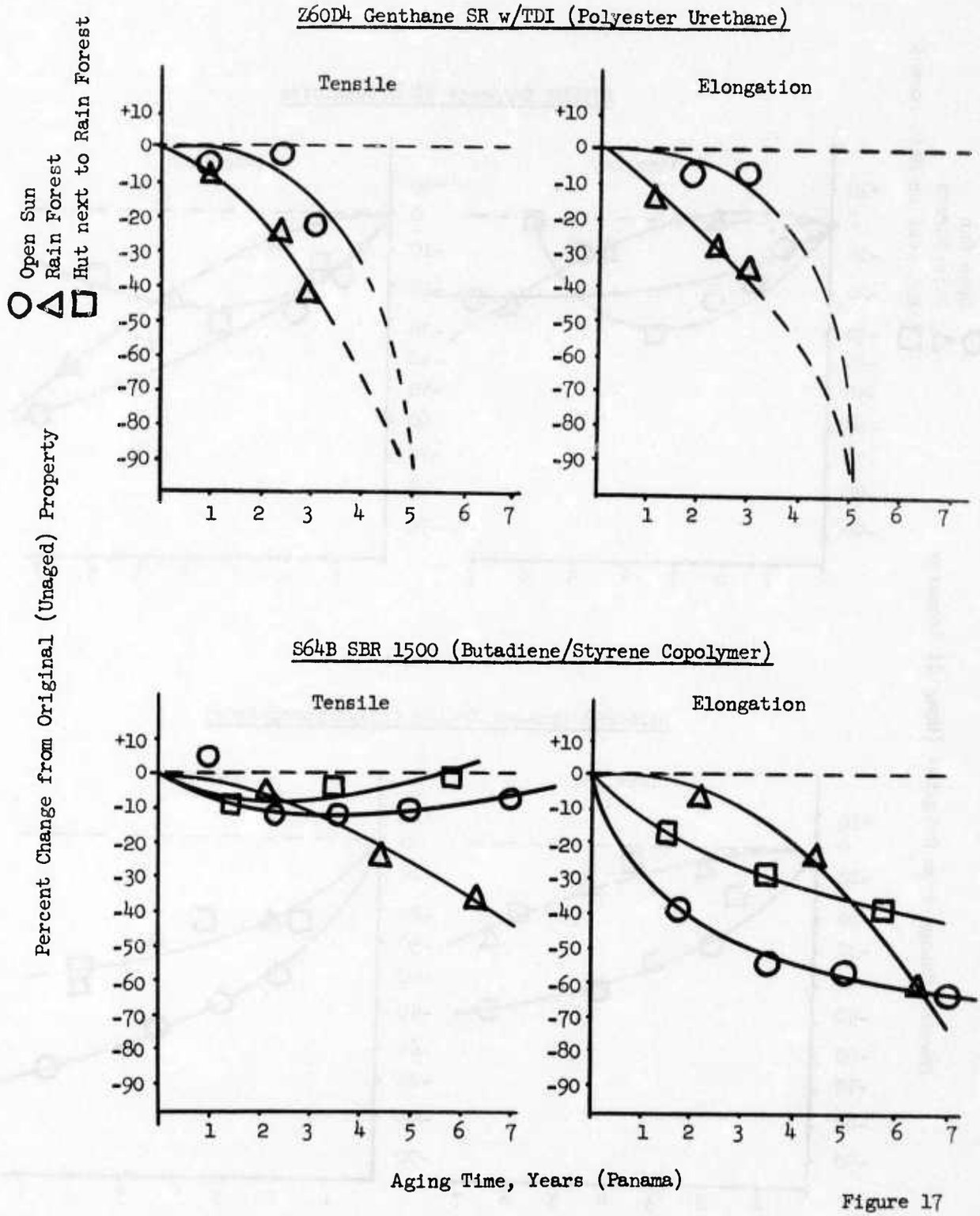

Z60D4 Genthane SR w/TDI (Polyester Urethane)
Tensile
Elongation
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1 2 3 4 5 6 7
S64B SBR 1500 (Butadiene/Styrene Copolymer)
Tensile
Elongation
Aging Time, Years (Panama)

Figure 17

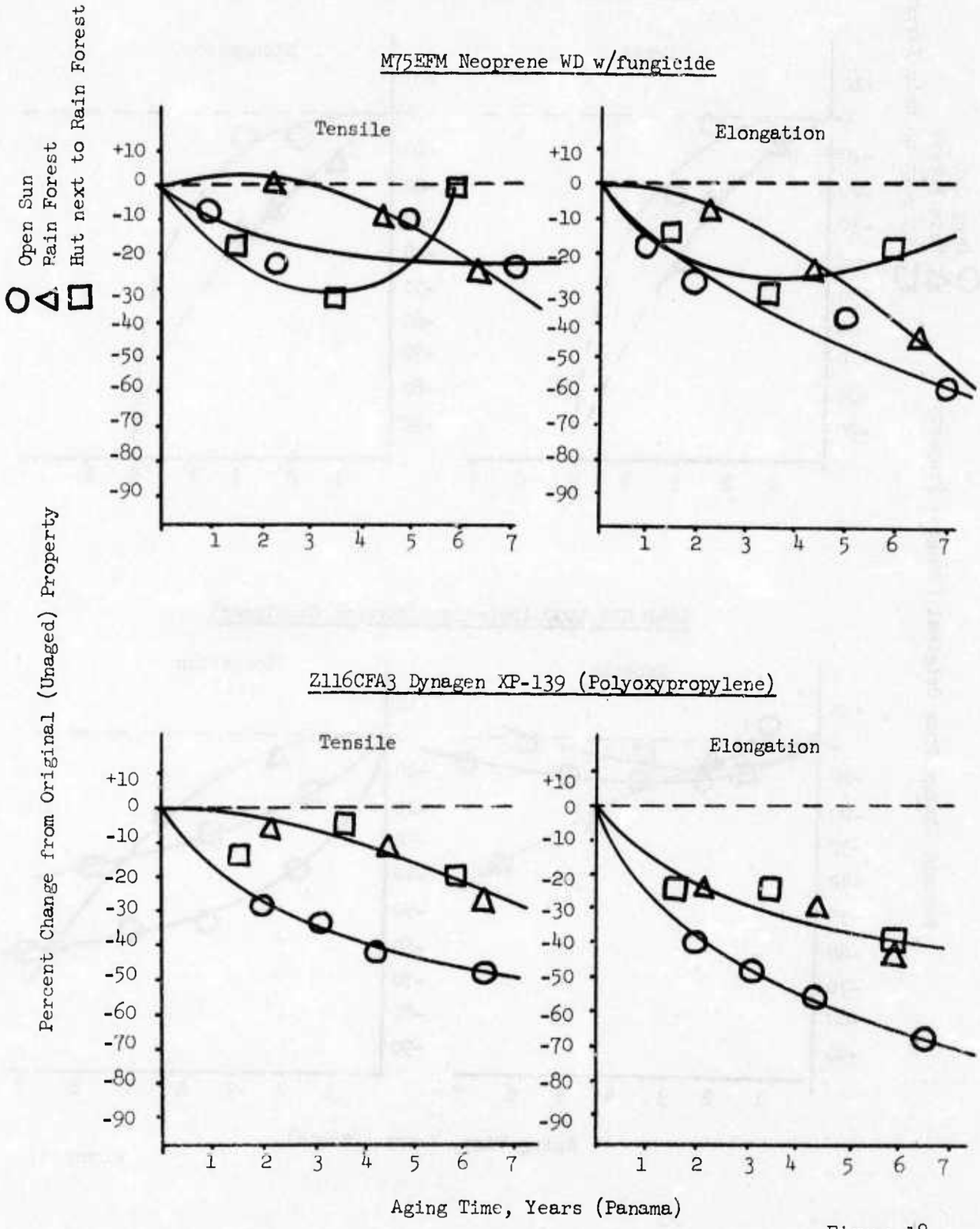

M75EFM Neoprene WD w/fungicide
Tensile
Elongation
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1 2 3 4 5 6 7
Z116CFA3 Dynagen XP-139 (Polyoxypropylene)
Tensile
Elongation
Aging Time, Years (Panama)

Figure 18

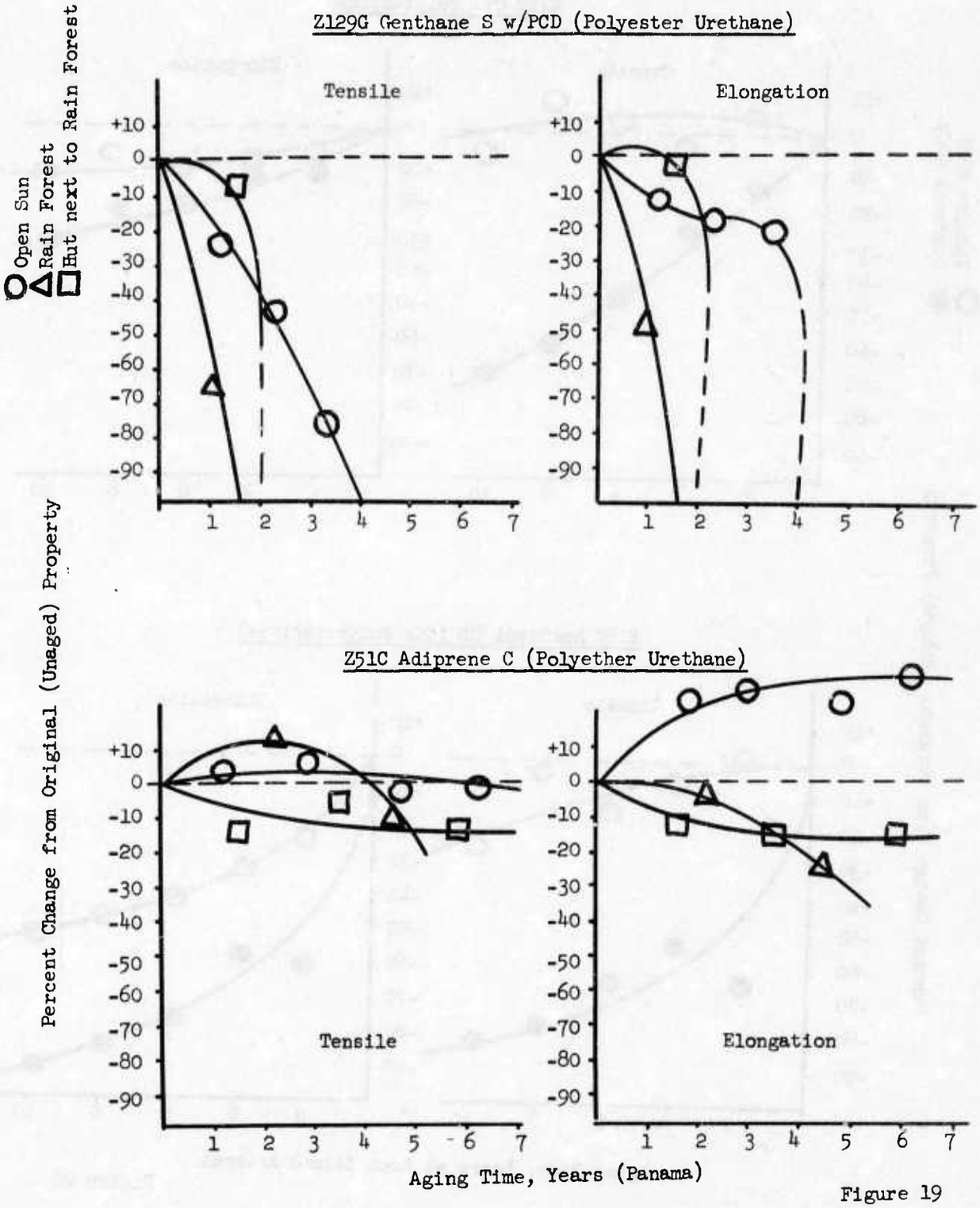

Z129G Genthane S w/PCD (Polyester Urethane)
Tensile
Elongation
Open Sun
Rain Forest
Hut next to Rain Forest
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
1
2
3
4
5
6
7
Z51C Adiprene C (Polyether Urethane)
Tensile
Elongation
Aging Time, Years (Panama)

Figure 19

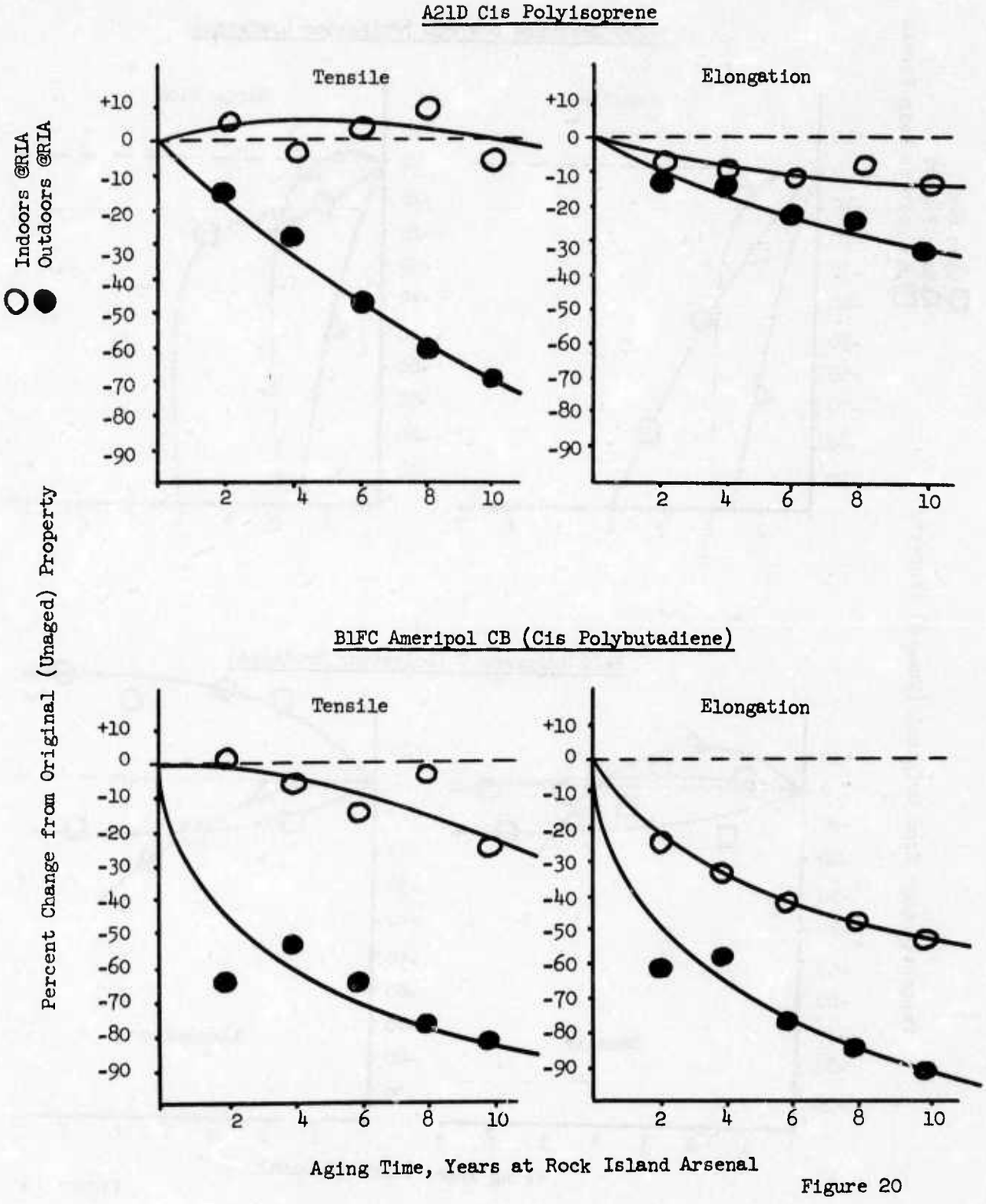
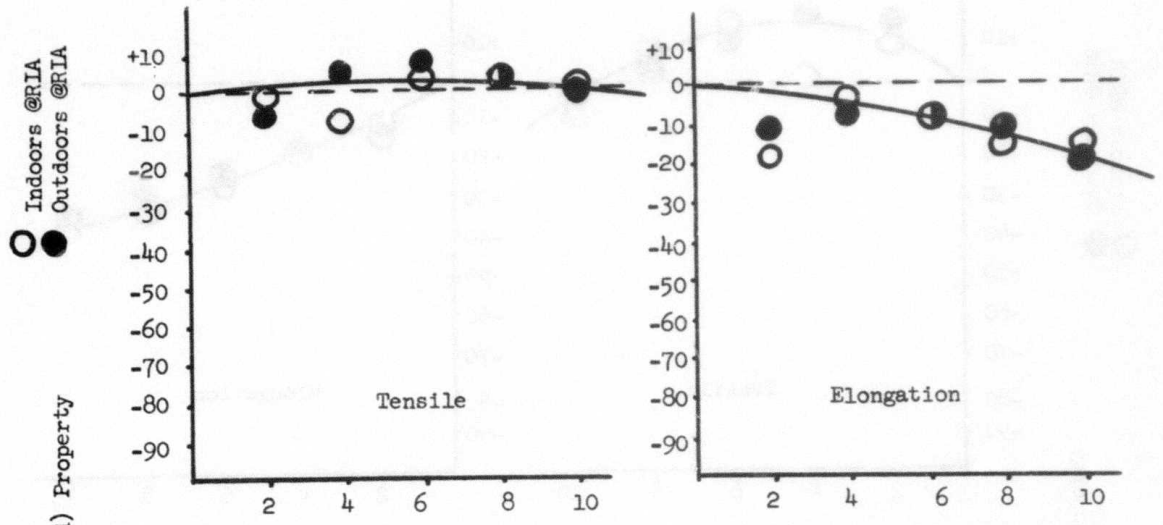
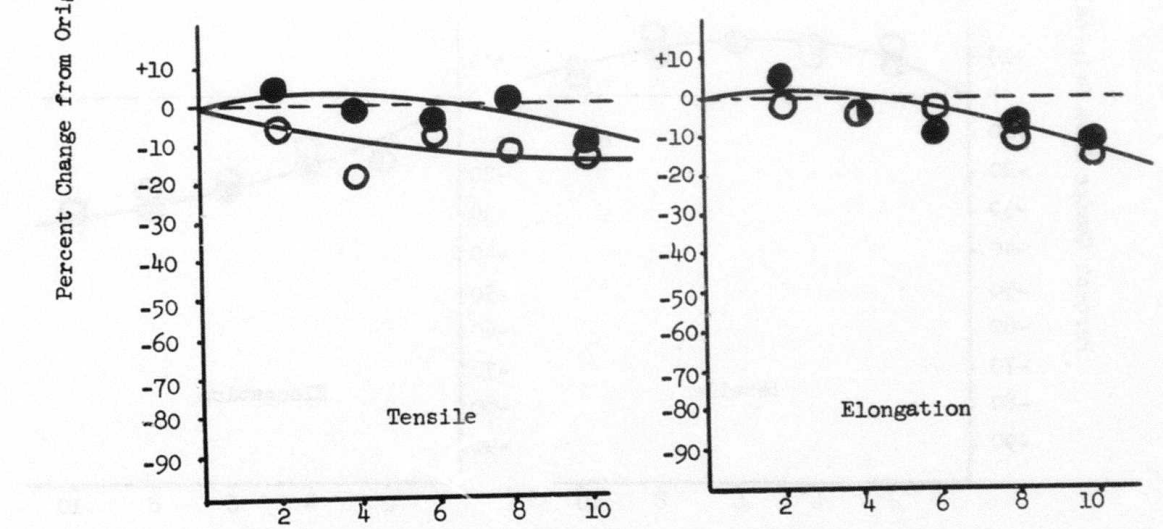

A21D Cis Polyisoprene
Tensile
Elongation
Indoors @RIA
Outdoors @RIA
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
B1FC Ameripol CB (Cis Polybutadiene)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years at Rock Island Arsenal

Figure 20

Z47F Hycar 4021 (Ethyl Acrylate/Chloroethyl Vinyl Ether)



Z107 (EPM MD460) Now EPR 404 (Ethylene/Propylene Copolymer)



Aging Time, Years at Rock Island Arsenal

Figure 21

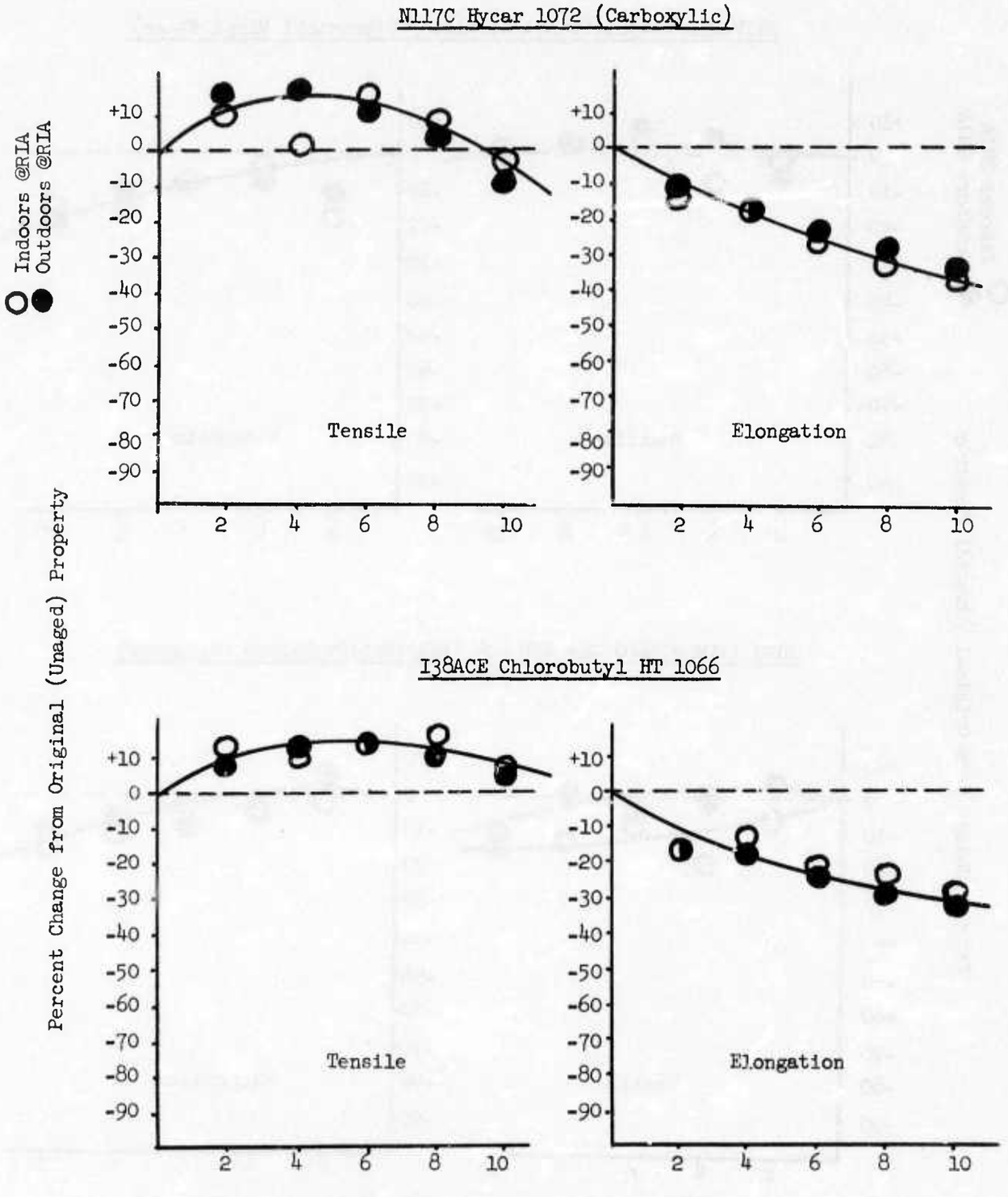

N117C Hycar 1072 (Carboxylic)
Indoors @RIA
Outdoors @RIA
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Tensile
Elongation
2
4
6
8
10
I38ACE Chlorobutyl HT 1066
Tensile
Elongation
Aging Time, Years at Rock Island Arsenal

Figure 22

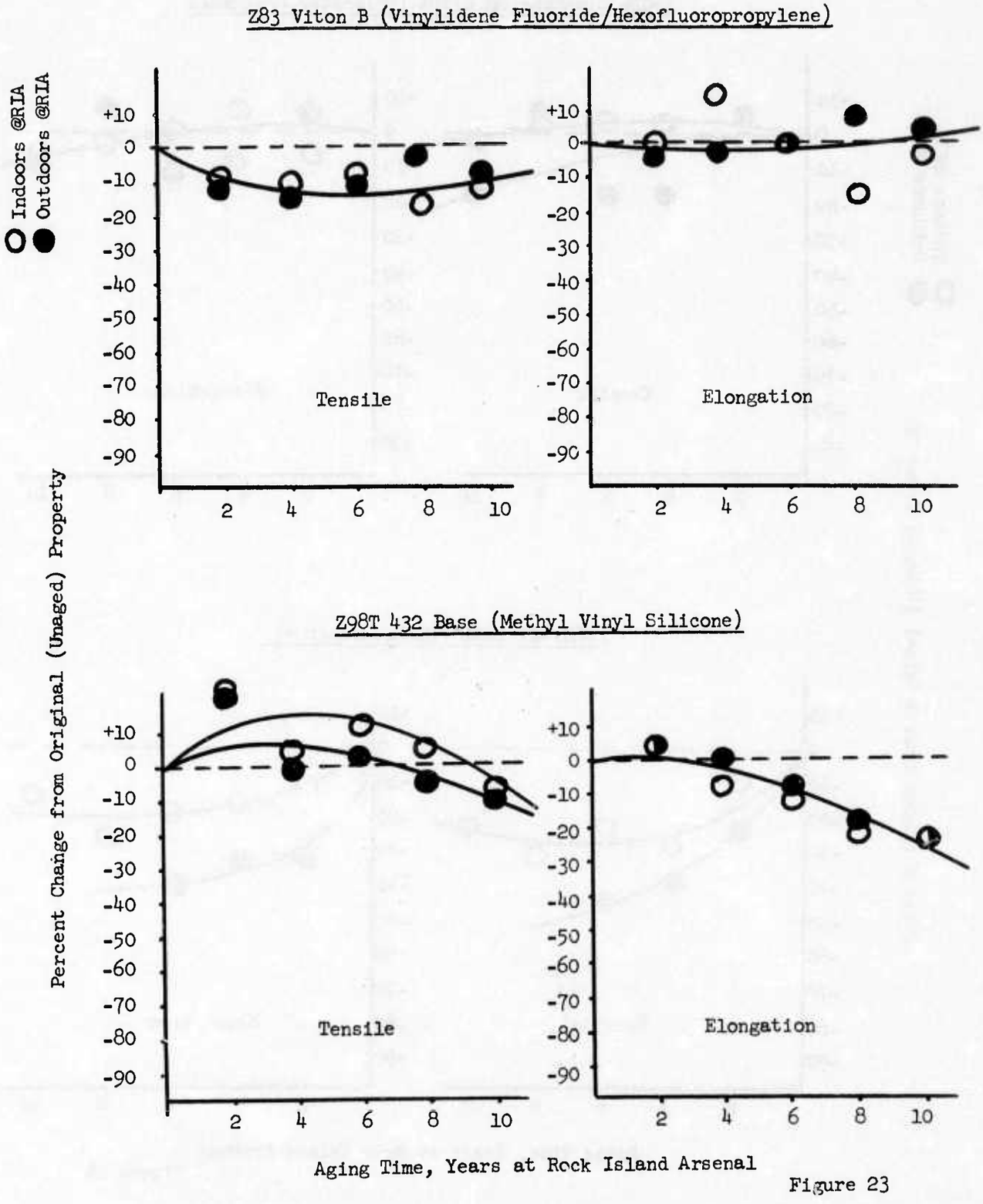

Z83 Viton B (Vinylidene Fluoride/Hexofluoropropylene)
Indoors @RIA
Outdoors @RIA
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Tensile
Elongation
2
4
6
8
10
Z98T 432 Base (Methyl Vinyl Silicone)
Percent Change from Original (Unaged) Property
Aging Time, Years at Rock Island Arsenal

Figure 23

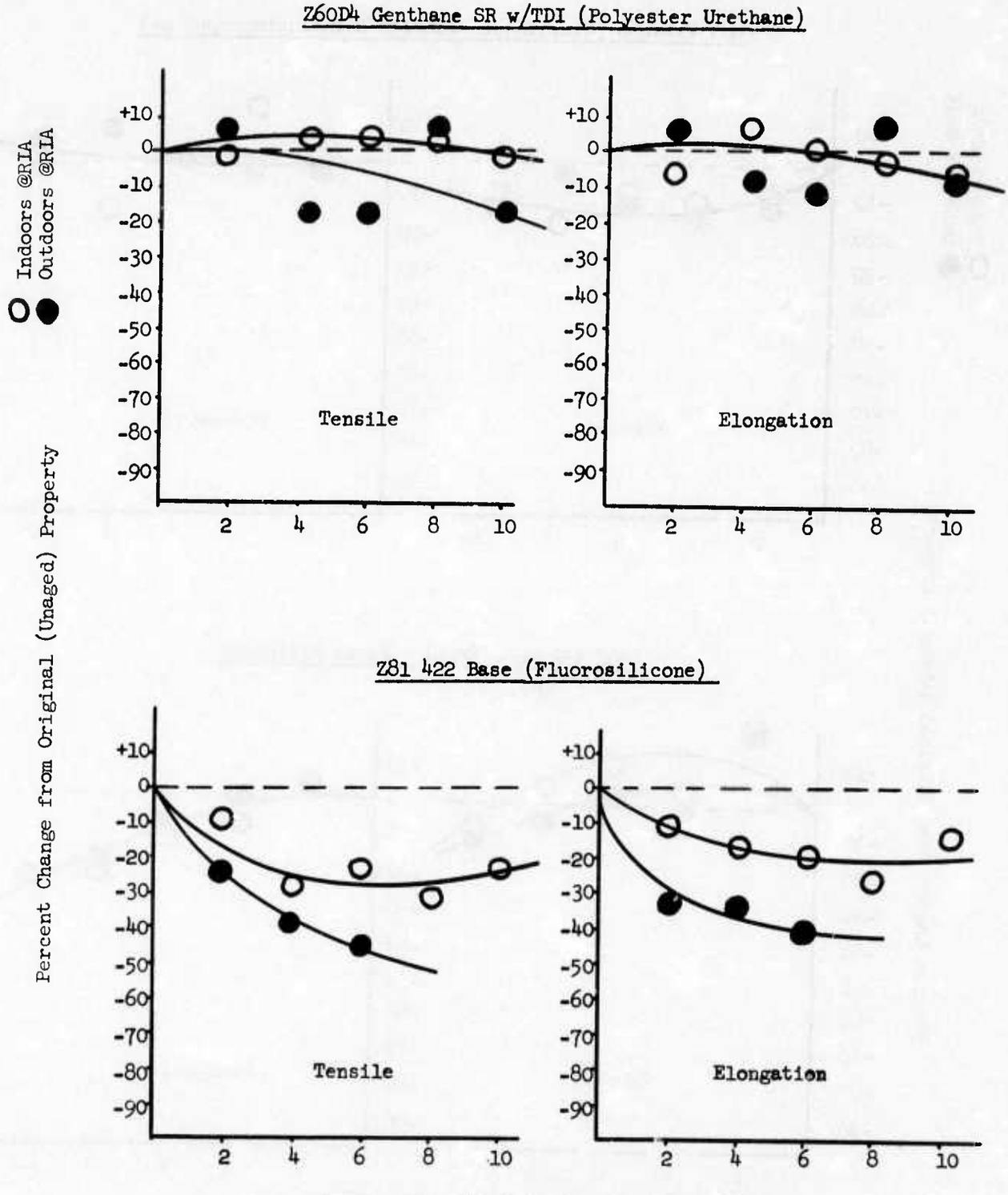

Z60D4 Genthane SR w/TDI (Polyester Urethane)
Indoors @RIA
Outdoors @RIA
Percent Change from Original (Unaged) Property
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
Tensile
Elongation
Z81 422 Base (Fluorosilicone)
Tensile
Elongation
Aging Time, Years at Rock Island Arsenal

Figure 24

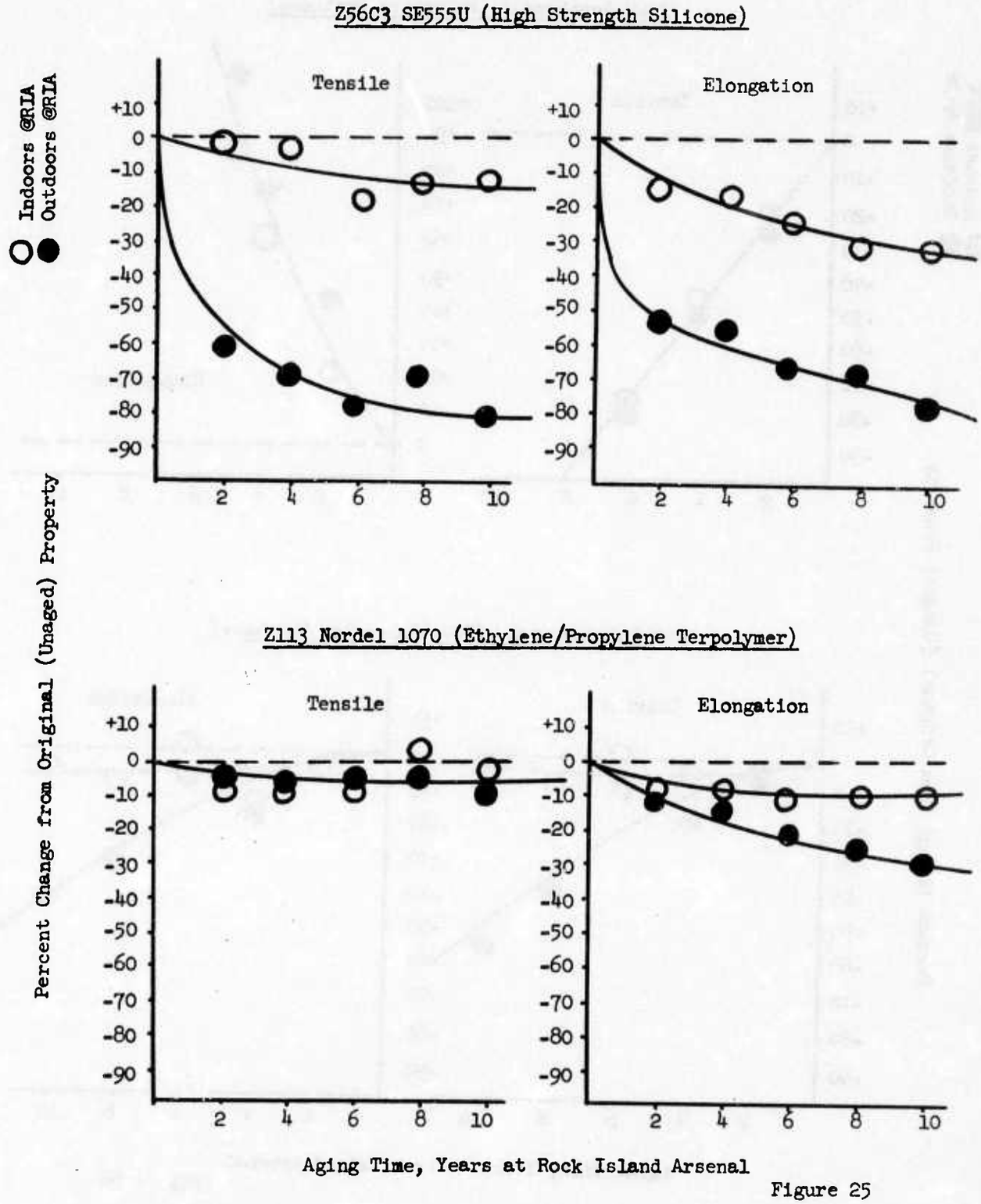

Z56C3 SE555U (High Strength Silicone)
Tensile
Elongation
Indoors @RIA
Outdoors @RIA
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2
4
6
8
10
Z113 Nordel 1070 (Ethylene/Propylene Terpolymer)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years at Rock Island Arsenal

Figure 25

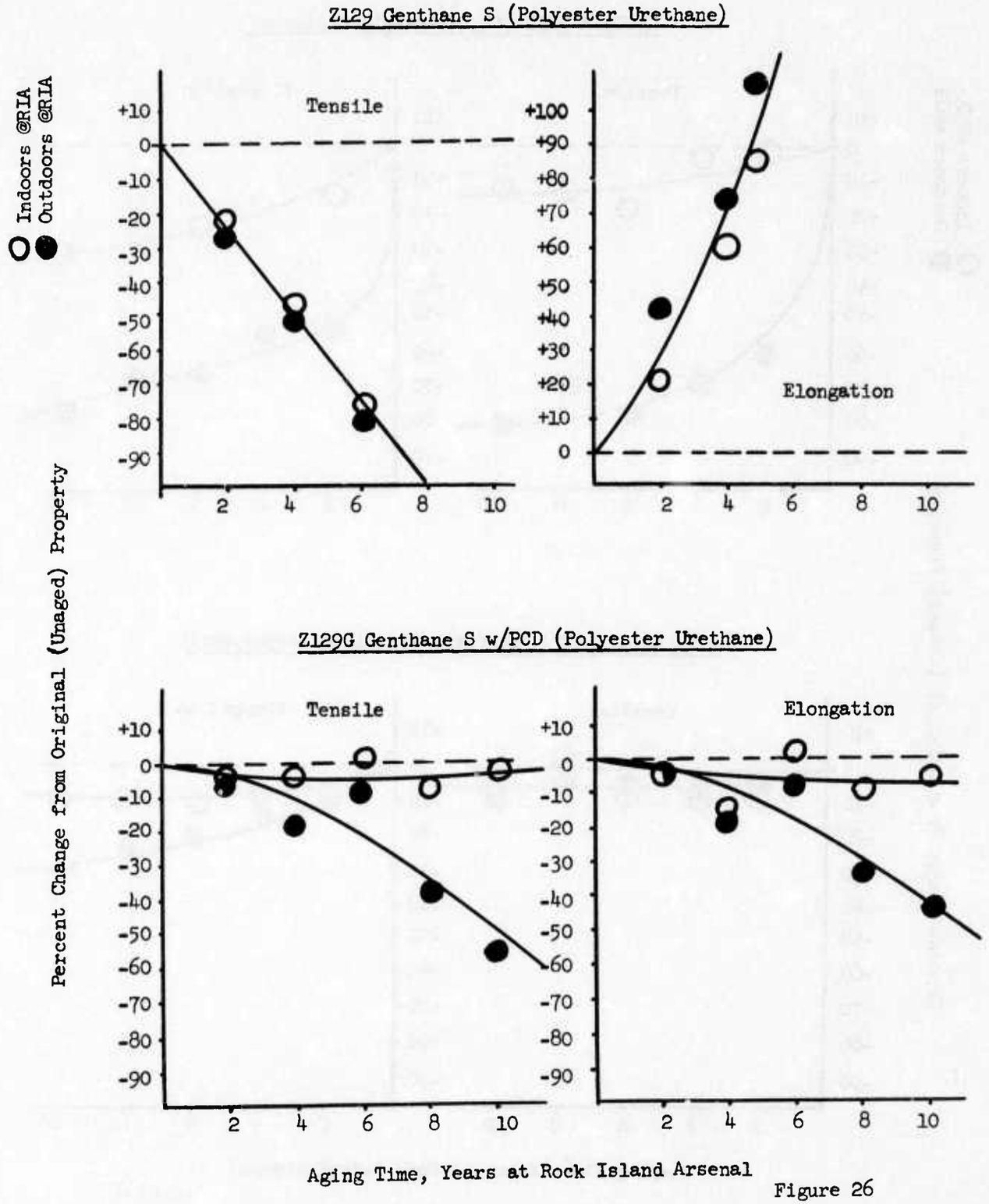

Z129 Genthane S (Polyester Urethane)
Indoors @RIA
Outdoors @RIA
Tensile
Elongation
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
+100
+90
+80
+70
+60
+50
+40
+30
+20
+10
2
4
6
8
10
Z129G Genthane S w/PCD (Polyester Urethane)
Tensile
Elongation
Percent Change from Original (Unaged) Property
Aging Time, Years at Rock Island Arsenal

Figure 26

Table 5
CHANGE IN TENSILE STRENGTH OF URETHANE VULCANIZATES AGED OUTDOORS IN PANAMA

Open Sun and Rain Forest

Aging Time Periods	U28-1 Genthane SR[1] (4 parts PCD) Open Sun	U28-1 Genthane SR[1] (4 parts PCD) Rain Forest	U29 Elastothane 455[1] (Peroxide Cure-4 parts PCD) Open Sun	U29 Elastothane 455[1] (Peroxide Cure-4 parts PCD) Rain Forest	U29-1 Elastothane 455[1] (Sulfur-Accelerator Cure) Open Sun	U29-1 Elastothane 455[1] (Sulfur-Accelerator Cure) Rain Forest	U30 Adiprene C[2] Open Sun	U30 Adiprene C[2] Rain Forest
Original (Unaged)	3620	3620	3500	3500	4630	4630	3170	3170
13 months	3530 (- 2)*	3220 (-11)	3260 (- 7)	1870 (-47)	2320	2720	3130 (- 1)	3310 (+ 4)
18 months	3710 (+ 2)	2220 (-39)	3450 (- 1)	1080 (-69)	430	1500	3170 (0)	3060 (- 3)
28 months	3410 (- 6)	1830 (-49)	2940 (-16)	1670 (-52)	Soft & tarlike	630	3440 (+ 9)	2720 (-11)
34 months	3240 (-10)	Soft & tarlike	2700 (-23)	290 (-92)		210	3210 (+ 1)	2790 (-12)
53 months	2350 (-35)		2250 (-36)	Soft & tarlike		Soft & tarlike	2960 (- 6)	2020 (-36)
60 months	1510 (-58)		1735 (-50)				2805 (-12)	2300 (-27)
72 months	Soft & tarlike		440 (-88)				2750 (-13)	2000 (-37)
84 months			Soft & tarlike				2850 (-10)	1765 (-44)

Rain Forest

Aging Time Periods	U31 Genthane S[1] (Mfgrs fungicide plus 4 parts PCD)	U35 Genthane SR[1] (Mfgrs fungicide A)	U35-1 Genthane SR[1] (Mfgrs fungicide A plus 4 parts PCD)	U35-2 Genthane SR[1] (Mfgrs fungicide A plus 4 parts TDI)	U35-3 Genthane SR[1] (Mfgrs fungicide B)	U35-4 Genthane SR[1] (Mfgrs fungicide B plus 4 parts PCD)	U35-5 Genthane SR[1] (Mfgrs fungicide B plus 4 parts TDI)	Z60D4 Genthane SR[1] (4 parts TDI)
Original (Unaged)	3910	3910	3480	4260	3190	2760	3590	3390
13 months	3810 (- 3)	1540 (-61)	3210 (- 8)	3750 (-12)	2790 (-13)	2680 (- 3)	3960 (+10)	3140 (- 7)
18 months	3880 (- 1)	590 (-85)	1750 (-50)	3240 (-24)	2270 (-29)	2560 (- 7)	3960 (+10)	2600 (-23)
28 months	4150 (+ 6)	Soft & tarlike	180 (-95)	2620 (-38)	1730 (-46)	2460 (-11)	3520 (- 2)	2610 (-23)
34 months	3470 (-11)		Soft & tarlike	2470 (-42)	Soft & tarlike	770 (-72)	3530 (- 2)	1975 (-42)
53 months	Soft & tarlike			Soft & tarlike		Soft & tarlike	2600 (-28)	Soft & tarlike
60 months							1855 (-48)	
72 months							1225 (-66)	
84 months							460 (-87)	
90 months							Soft & tarlike	

Aging Time Periods	U34 Witco MG2[1]	U42 Cyanaprene D5[1]	U43 Texin 355D[1]	U43-1 Texin 480A[1]	U43-2 Texin 480A[1] (Hydrolysis Stabilizer Added)	U44 Niax D540[3]	U45 Genthane S[1] (4 parts TDI)	U17-226[4] RIA MG 1-129 (Sulfur-Accelerator Cure)	U17-229[4] RIA MG 1-129 (Peroxide Cure)
Original (Unaged)	4280	5320	5080	6970	7570	4670	4840	2790	2150
13 months	3250 (-24)	3750 (-30)	4230 (-17)	4250 (-35)	5490 (-26)	4040 (-13)	4780 (- 1)	3000 (+ 8)	1960 (- 9)
27 months	2380 (-44)	3800 (-29)	3440 (-32)	1720 (-75)	3540 (-53)	3550 (-24)	3050 (-37)	2610 (- 6)	1790 (-17)
39 months	Soft & tarlike	1230 (-79)	2350 (-54)	1090 (-84)	4370 (-42)	3440 (-26)	1790 (-63)	2940 (+ 5)	1880 (-13)
51 months		Pad Brittle	1745 (-66)	580 (-92)	6285 (-17)	Soft & tarlike	Soft & tarlike	---	---
64 months			1640 (-68)	Pad Brittle	4735 (-37)			2525 (- 9)	1720 (-20)

*Values in parentheses are percent change from original (unaged) values

Table 5
(Continued)

Open Sun and Rain Forest

Aging Time Periods	U56 Thiokol ZR625[1] (Sulfur cure) Open Sun	U56 Thiokol ZR625[1] (Sulfur cure) Rain Forest	U56-1 Thiokol ZR625[1] (Sulfur cure plus 4 parts PCD) Open Sun	U56-1 Thiokol ZR625[1] (Sulfur cure plus 4 parts PCD) Rain Forest	U56-2 Thiokol ZR625[1] (Peroxide cure) Open Sun	U56-2 Thiokol ZR625[1] (Peroxide cure) Rain Forest	U56-3 Thiokol ZR625[1] (Peroxide cure plus 4 parts PCD) Open Sun	U56-3 Thiokol ZR625[1] (Peroxide cure plus 4 parts PCD) Rain Forest
Original (Unaged)	4820	4820	4960	4960	3840	3840	3850	3850
14 months	3800 (-21)*	4050 (-16)	4170 (-16)	3790 (-24)	3260 (-15)	2260 (-41)	3310 (-14)	2050 (-47)
26 months	2290 (-52)	3250 (-33)	3570 (-28)	2910 (-41)	---	1650 (-57)	2940 (-24)	1340 (-65)
38 months	565 (-88)	2190 (-55)	2675 (-46)	2820 (-43)	1300 (-66)	390 (-90)	2310 (-40)	1350 (-65)
51 months	Soft & tarlike	820 (-83)	2505 (-49)	2135 (-57)	455 (-88)	Soft & tarlike	1760 (-54)	Soft & tarlike
63 months		160 (-97)	1690 (-66)	2225 (-55)	Soft & tarlike		1735 (-55)	

Aging Time Periods	Estane 58300[6] Open Sun	Estane 58300[6] Rain Forest	Estane 58304[1] Open Sun	Estane 58304[1] Rain Forest	Estane 58013[6] Open Sun	Estane 58013[6] Rain Forest
Original (Unaged)	2800	2880	5440	5440	2810	2810
14 months	680 (-76)	990 (-66)	4330 (-20)	4770 (-12)	2800 (0)	2710 (- 4)
38 months	Breaks when bent	Breaks when bent	1525 (-72)	5485 (+ 1)	---	2810 (0)
63 months			535 (-90)	3735 (-31)	2345 (-17)	2370 (-16)

Aging Time Periods	U57 X29-83 (2092-60D) (Upjohn)[1] Open Sun	U57 X29-83 (2092-60D) (Upjohn)[1] Rain Forest	U57-1 (CPR 2092-90A) (Upjohn)[1] Open Sun	U57-1 (CPR 2092-90A) (Upjohn)[1] Rain Forest	U57-2 X29-77A (2094-90A) (Upjohn)[2] Open Sun	U57-2 X29-77A (2094-90A) (Upjohn)[2] Rain Forest
Original (Unaged)	7060	7060	6440	6440	4000	4000
14 months	5600 (-21)	6180 (-12)	1360 (-79)	4040 (-37)	3380 (-16)	4340 (+ 9)
25 months	2710 (-62)	4840 (-31)	750 (-87)	3190 (-49)	3370 (-16)	4140 (+ 4)
50 months	Brittle	3230 (-54)	Brittle	800 (-88)	1700 (-58)	4000 (0)

Aging Time Periods	U79 Texin 591A[1] Open Sun	U79 Texin 591A[1] Rain Forest	U79-1 Texin XP275[1] (Contains hydrolysis stabilizer and carbon black for UV) Open Sun	U79-1 Texin XP275[1] (Contains hydrolysis stabilizer and carbon black for UV) Rain Forest	U79-2 Texin 355DXH[1] (Contains hydrolysis inhibitor) Open Sun	U79-2 Texin 355DXH[1] (Contains hydrolysis inhibitor) Rain Forest	U79-3 Texin XPE-290[2] (Contains carbon black as UV inhibitor) Open Sun	U79-3 Texin XPE-290[2] (Contains carbon black as UV inhibitor) Rain Forest	U79-4 Texin XPE-290[2] (Contains UV stabilizer) Open Sun	U79-4 Texin XPE-290[2] (Contains UV stabilizer) Rain Forest
Original (Unaged)	7940	7940	7250	7250	6500	6500	7940	7940	6970	6970
12 months	2855 (-64)	7250 (- 9)	5945 (-18)	7260 (0)	2415 (-63)	3665 (-44)	5405 (-32)	6180 (-22)	2205 (-68)	3240 (-53)
25 months	Brittle	4405 (-45)	3745 (-48)	5085 (-30)	990 (-85)	2125 (-66)	6210 (-22)	5210 (-34)	1045 (-85)	6000 (-14)
37 months		3755 (-53)	1610 (-78)	4565 (-37)	Brittle	3055 (-53)	5970 (-25)	5515 (-31)	930 (-87)	5295 (-24)

*Values in parentheses are percent change from original (unaged) values

Table 5
(Continued)

Open Sun and Rain Forest

Aging Time Periods	U83 CPR 2102-80A[1] Open Sun	U83 CPR 2102-80A[1] Rain Forest	U83-1 CPR 2102-90A[1] Open Sun	U83-1 CPR 2102-90A[1] Rain Forest	U83-2 CPR 2102-55D[1] Open Sun	U83-2 CPR 2102-55D[1] Rain Forest	U83-3 CPR 2103-80A[2] Open Sun	U83-3 CPR 2103-80A[2] Rain Forest	U83-4 CPR 2103-55D[2] Open Sun	U83-4 CPR 2103-55D[2] Rain Forest
Original (Unaged)	7630	7630	8840	8840	8130	8130	7060	7060	6540	6540
12 months	875 (-89)*	4000 (-49)	2000 (-77)	6250 (-29)	4635 (-43)	7765 (- 4)	1675 (-76)	6160 (-13)	4690 (-28)	6525 (0)

Aging Time Periods	U83-5 CPR 2353-80A[5] Open Sun	U83-5 CPR 2353-80A[5] Rain Forest	U83-6 CPR 2353-55D[5] Open Sun	U83-6 CPR 2353-55D[5] Pain Forest
Original (Unaged)	6050	6050	5830	5830
12 months	760 (-87)	2540 (-58)	2350 (-58)	4125 (-29)

1. Polyester Urethane
2. Polyether Urethane
3. Caprolactone Urethane
4. Polyether Urethane-Urea
5. Polyester/Polyether Urethane
6. Unknown

*Values in parentheses are percent change from original (unaged) values

Vulcanizates based on the polyether urethane-urea elastomers[6] synthesized by this laboratory continue to remain virtually unaffected after 64 months of exposure.

Ethylene-propylene terpolymer (EPDM) elastomers have wide usefulness as antiozonants for diene elastomers and may be used where chemical antiozonants function only poorly or not at all.[7] Several diene/ethylene-propylene (EPDM) blended vulcanizates were exposed outdoors at Rock Island and Panama since issuance of the previous report[2] on this subject. The effect of outdoor exposure on these vulcanizates is shown in Table 6. Results, to date, indicate that blended vulcanizates exposed in the open sun in Panama are less age-resistant than when exposed in the open sun at Rock Island, Illinois, on the basis of percent changes in elongation from the original values. Also, SBR 1500 vulcanizates blended with various EPDM elastomers (compounds S206-5, S209-1, and S209-2) have significantly better age-resistance when exposed in the rain forest in Panama than does the unblended SBR 1500 control compound (S211). On the other hand, results show that there is a significant loss in tensile strength of the pale crepe/EPDM blended vulcanizate (A11A1C2) when exposed in the open sun at both Rock Island and Panama which indicates that the excellent aging characteristics of the EPDM elastomer are not transmitted to this blend.

Additional test pads prepared from elastomers, which have become commercially available since this program was initiated, have also been exposed outdoors at Rock Island and at Panama. Results to date are shown in Table 7. The Hydrin 200 vulcanizate has shown excellent age resistance thus far after seven years of exposure in the Panama rain forest.

Results for bent-loop specimens (ASTM D518, Method B) of various vulcanizates, with and without antiozonants, exposed in the open sun at Rock Island, Alaska, and Panama are shown in Table 8. In general, those vulcanizates known to be susceptible to ozone attack (SBR 1500, Paracril 18-80, Ameripol CB, Hycar 1072, and pale crepe, for example), which are inhibited with chemical antiozonants, exhibit cracking earlier at Panama than they do at Rock Island or Alaska. One notable exception to this general observation is found in the Paracril 18-80 vulcanizates inhibited with solid antiozonants (N87B67, N87B22 and N87B58) which cracked sooner in Alaska than in Panama. The vulcanizates containing liquid antiozonants (N87B33 and N87B73) followed the general rule of cracking sooner in Panama than in Alaska. Interestingly, vulcanizates based on SBR 1500, Paracril 18-80, and pale crepe that were blended with EPDM (A11A1C2, N87D4C2, S77D10C2, S206-5, S209-1 and S209-2) have remained crack-free outdoors at Panama and Rock Island for a period of five years thus far. The value of using EPDM as a polymeric antiozonant is further enhanced from another standpoint. When the unstressed test pads are received from the exposure sites after various periods of aging, bent-loop

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[6] Ossefort, Z.T. and Veroeven, W.M., "Synthesis and Properties of Low Temperature Oil-Resistant Millable Polyether Urethane-Urea Elastomers", I&EC, Product Research and Development, Vol. 6, p. 2, March 1967.

[7] Ossefort, Z.T. and Bergstrom, E.W., "Ethylene-Propylene Rubbers", Rubber Age, Vol. 101, No. 9, pp. 47-60, September 1969.

[2] Bergstrom, E.W., Ibid.

Table 6
OUTDOOR AGING PROPERTIES OF VULCANIZATES PREPARED FROM ELASTOMERS BLENDED WITH EPDM

S211 (100 SBR 1500 - Control)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	3910	4090 (+ 5)*	4045 (+ 3)	3675 (+ 6)	3420 (-13)	2695 (-31)	2240 (-43)
Modulus, 300%, psi	1940	2510 (+29)	2810 (+45)	3020 (+56)	3385 (+74)	2695 (+39)	---
Elongation, %	480	430 (-10)	400 (-17)	360 (-25)	320 (-33)	300 (-38)	270 (-44)
Hardness, Shore A	66	70 (+ 6)	71 (+ 8)	72 (+ 9)	74 (+12)	69 (- 5)	71 (+ 8)
Strain, 400 psi for 60 sec., %	141	118 (-16)	106 (-25)	100 (-29)	89 (-37)	118 (-16)	107 (-24)

S206-5 (80/40 SBR 1500/Royalene 400)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	3020	3020 (0)	2915 (- 3)	3240 (+ 7)	2845 (- 6)	2845 (- 6)	3050 (+ 1)
Modulus, 300%, psi	1020	1500 (+47)	1565 (+63)	1660 (+63)	1775 (+74)	1625 (+59)	1540 (+51)
Elongation, %	580	500 (-14)	450 (-22)	470 (-19)	420 (-28)	480 (-17)	480 (-17)
Hardness, Shore A	57	60 (+ 5)	60 (+ 5)	61 (+ 7)	65 (+14)	59 (+ 4)	62 (+ 9)
Strain. 400 psi for 60 sec., %	192	161 (-16)	145 (-24)	157 (-18)	136 (-29)	163 (-15)	148 (-23)

S209-1 (70/30 SBR 1500/EP syn 55)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	3410	3540 (+ 4)	3390 (- 1)	3435 (+ 1)	3235 (- 5)	3270 (- 4)	3305 (- 3)
Modulus, 300%, psi	2000	2620 (+31)	2825 (+41)	2840 (+42)	3140 (+57)	2580 (+29)	2770 (+39)
Elongation, %	440	380 (-14)	330 (-25)	350 (-20)	310 (-30)	360 (-18)	340 (-23)
Hardness, Shore A	69	70 (+ 1)	71 (+ 3)	73 (+ 6)	76 (+10)	70 (+ 1)	73 (+ 6)
Strain, 400 psi for 60 sec., %	121	101 (-17)	95 (-21)	95 (-21)	77 (-36)	101 (-17)	100 (-17)

S209-2 (70/30 SBR 1500/Vistalon 6505)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	3480	3530 (+ 1)	3315 (- 5)	3390 (- 3)	3325 (- 4)	2830 (-19)	3275 (- 6)
Modulus, 300%, psi	1870	2450 (+31)	2605 (+39)	2765 (+48)	3000 (+60)	2665 (+43)	2570 (+37)
Elongation, %	470	410 (-13)	380 (-19)	360 (-23)	340 (-28)	320 (-32)	350 (-26)
Hardness, Shore A	70	72 (+ 3)	75 (+ 7)	75 (+ 7)	76 (+ 9)	71 (+ 1)	73 (+ 4)
Strain, 400 psi for 60 sec., %	131	108 (-18)	92 (-30)	92 (-30)	82 (-37)	105 (-12)	93 (-29)

*Values in parentheses are percent change from original (unaged) values

Table 6
(Continued)

A11A1C2 (70/30 Pale Crepe/Nordel 1070)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	3040	2800 (- 8)*	1745 (-43)	2400 (-21)	1195 (-67)	2800 (- 8)	2155 (-29)
Modulus, 300%, psi	1690	2020 (+20)	1650 (- 2)	1890 (+12)	1150 (-32)	2240 (+33)	2050 (+21)
Elongation, %	480	420 (-13)	360 (-25)	390 (-19)	320 (-33)	380 (-21)	320 (-33)
Hardness, Shore A	63	71 (+13)	70 (+11)	69 (+10)	70 (+11)	70 (+11)	68 (+ 8)
Strain, 400 psi for 60 sec., %	129	107 (-17)	121 (- 6)	108 (-16)	150 (+16)	101 (-22)	102 (-21)

N8TD4C2 (70/30 Paracril 18-80/Nordel 1070)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	2040	2040 (0)	1625 (-20)	1870 (- 8)	1490 (-27)	1780 (-13)	1875 (- 8)
Modulus, 300%, psi	1630	2040 (+25)	---	---	---	---	---
Elongation, %	360	300 (-17)	240 (-33)	250 (-31)	200 (-44)	250 (-31)	250 (-31)
Hardness, Shore A	70	75 (+ 7)	75 (+ 7)	76 (+ 9)	78 (+11)	74 (+ 6)	72 (+ 3)
Strain, 400 psi for 60 sec., %	108	92 (-15)	69 (-36)	70 (-35)	73 (-32)	75 (-31)	69 (-36)

S77D10C2 (70/30 SBR 1500/Nordel 1070)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years	Panama Sunlight 2 Years	Panama Sunlight 4 Years	Panama Rain Forest 2 Years	Panama Rain Forest 4 Years
Tensile, psi	2700	2850 (+ 6)	2680 (- 1)	2940 (+28)	2410 (-11)	2800 (+ 4)	2595 (- 4)
Modulus, 300%, psi	1430	1920 (+34)	2140 (+50)	2320 (+62)	2365 (+65)	1950 (+36)	1955 (+37)
Elongation, %	500	420 (-16)	370 (-26)	390 (-22)	310 (-38)	410 (-18)	380 (-24)
Hardness, Shore A	62	71 (+15)	70 (+13)	73 (+18)	73 (+18)	70 (+13)	69 (+11)
Strain, 400 psi for 60 sec., %	140	120 (-14)	110 (-21)	104 (-26)	96 (-31)	124 (-11)	119 (-15)

S202 (70/30 SBR 1500/Nordel 1470)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years
Tensile, psi	3080	2920 (- 5)	2850 (- 7)
Modulus, 300%, psi	2410	2340 (- 3)	2680 (+11)
Elongation, %	350	350 (0)	320 (- 9)
Hardness, Shore A	67	70 (+ 4)	72 (+ 7)
Strain, 400 psi for 60 sec., %	116	114 (- 2)	88 (-24)

S202-1 (70/30 Stereon 720/Nordel 1440)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Rock Island Arsenal Sunlight 4 Years
Tensile, psi	2290	2120 (- 7)	1810 (-21)
Modulus, 300%, psi	2160	---	---
Elongation, %	310	260 (-16)	200 (-35)
Hardness, Shore A	74	77 (+ 4)	77 (+ 4)
Strain, 400 psi for 60 sec., %	102	88 (-14)	69 (-32)

*Values in parentheses are percent change from original (unaged) values.

Table 7

OUTDOOR AGING PROPERTIES OF VULCANIZATES PREPARED FROM ELASTOMERS WHICH BECAME AVAILABLE COMMERCIALLY AFTER ORIGINAL TEST PROGRAM WAS INITIATED

Z173 (Hydrin 200)

	Original (Unaged)	Panama Rain Forest 1 Year	3 Years	5 Years	7 Years
Tensile, psi	1680	1800 (+ 7)*	1800 (+ 7)	1950 (+16)	1875 (+12)
Modulus, 300%, psi	910	890 (- 2)	1040 (+14)	1320 (+31)	1135 (+25)
Elongation, %	600	620 (+ 3)	510 (-15)	470 (-22)	540 (-10)
Hardness, Shore A	55	59 (+ 7)	53 (- 4)	59 (+ 7)	58 (+ 5)
Strain, 400 psi for 60 sec., %	---	155	148	143	155

U65 (Vibrathane 5004)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	4 Years	Panama Sunlight 2 Years	4 Years	Rain Forest 2 Years	4 Years
Tensile, psi	4380	4500 (+27)	3255 (-26)	3190 (-27)	1630 (-63)	2190 (-50)	Deteriorated too badly to test after 3 years.
Modulus, 300%, psi	---	---	---	---	---	---	
Elongation, %	290	280 (- 3)	240 (-17)	220 (-24)	220 (-24)	190 (-34)	
Hardness, Shore A	78	79 (+ 1)	78 (0)	77 (- 1)	77 (- 1)	76 (- 3)	
Strain, 400 psi for 60 sec., %	50	41 (-18)	44 (-12)	47 (- 6)	77 (+54)	58 (+16)	

S227-2 (Stereon 750)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Panama Sunlight 2 Years	Rain Forest 2 Years
Tensile, psi	2670	2630 (- 2)	2295 (-14)	2180 (-18)
Modulus, 300%, psi	860	1310 (+52)	1660 (+93)	1510 (+76)
Elongation, %	680	580 (-15)	420 (-38)	410 (-40)
Hardness, Shore A	55	65 (+18)	68 (+24)	68 (+24)
Strain, 400 psi for 60 sec., %	184	144 (-22)	121 (-34)	126 (-32)

U75-1 (Adiprene CM)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Panama Sunlight 2 Years	Rain Forest 2 Years
Tensile, psi	4760	4350 (- 5)	3735 (-22)	4100 (-14)
Modulus, 300%, psi	1850	2060 (+11)	1950 (+ 5)	1925 (+ 4)
Elongation, %	560	520 (- 7)	490 (-13)	500 (-11)
Hardness, Shore A	65	67 (+ 3)	65 (0)	65 (0)
Strain, 400 psi for 60 sec., %	121	128 (+ 6)	123 (+ 2)	123 (+ 2)

*Values in parentheses are percent change from original (unaged) values.

Table 7
(Continued)

B33-4 (HYTRANS 1227-176-2) (Alfin Rubber)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Panama Sunlight 2 Years	Panama Rain Forest 2 Years
Tensile, psi	3050	2745 (-10)*	2385 (-22)	2120 (-30)
Modulus, 300%, psi	490	1020 (+108)	1715 (+250)	1235 (+152)
Elongation, %	770	620 (-19)	400 (-48)	440 (-43)
Hardness, Shore A	55	66 (+20)	70 (+27)	67 (+22)
Strain, 400 psi for 60 sec., %	283	205 (-28)	133 (-53)	178 (-38)

S223-4 (HYTRANS 1227-176-1) (Alfin Rubber)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Panama Sunlight 2 Years	Panama Rain Forest 2 Years
Tensile, psi	3060	2805 (- 8)	2635 (-14)	2290 (-25)
Modulus, 300%, psi	430	835 (+94)	1380 (+221)	1080 (+151)
Elongation, %	840	690 (-18)	500 (-40)	510 (-39)
Hardness, Shore A	54	63 (+17)	69 (+28)	67 (+24)
Strain, 400 psi for 60 sec., %	306	234 (-24)	163 (-47)	194 (-37)

G44 (Dow 746U Silicone - No postcure type)

	Original (Unaged)	Rock Island Arsenal Sunlight 2 Years	Panama Sunlight 2 Years	Panama Rain Forest 2 Years
Tensile, psi	990	900 (- 9)	920 (- 7)	1065 (+ 8)
Modulus, 300%, psi	---	---	---	---
Elongation, %	270	220 (-19)	240 (-11)	250 (- 7)
Hardness, Shore A	55	53 (- 4)	55 (0)	55 (0)
Strain, 400 psi for 60 sec., %	125	125 (0)	145 (+16)	123 (- 2)

*Values in parentheses are percent change from original (unaged) values.

Table 8
TIME TO FIRST CRACK FOR BENT-LOOP SPECIMENS
EXPOSED OUTDOORS IN THE OPEN SUN
AT ROCK ISIAND, ILLINOIS, ALASKA, AND PANAMA

RIA CPD. NO.	ELASTOMER TYPE AND ANTIOZONANT	TIME TO FIRST CRACK		
		PANAMA	ROCK ISLAND	ALASKA
A21D	Cis-polyisoprene	<1W	5D	<6M
Z107	EPM (Enjay MD460 - Now 404)	>6M <12M	30M	>8 Yr <10 Yr
Z60D4	Genthane SR	<6M	OK 10 Yr	>8 Yr <10 Yr
Z60D4M	Genthane SR - 2 parts/100 rhc fungicide	<6M	OK 10 Yr	>8 Yr <10 Yr
I38ACE	Chlorobutyl HT 1066	>6M <12M	16W	>5 Yr <6 Yr
Z47F	Hycar 4021	>6M <12M	29M	>8 Yr <10 Yr
Z83	Viton B	OK 10 Yr	OK 10 Yr	OK 10 Yr
Z56C3	SE555U High Strength Silicone	OK 10 Yr	OK 10 Yr	OK 10 Yr
Z98T	Silastic 432 Base (Methyl Vinyl Silicone)	OK 10 Yr	OK 10 Yr	OK 10 Yr
Z81F	Silastic 422 Base (Fluorosilicone)	OK 10 Yr	OK 10 Yr	OK 10 Yr
M75EF	Neoprene WD	>16M <21M	26M	OK 10 Yr
M75EFM	Neoprene WD-2 parts/100 rhc fungicide	>12M <16M	26M	>8 Yr <10 Yr
S64	SBR 1500	<1W	5D	<6M
S64B	Same as S64 plus 3 parts U.O.P. 88	>33M <40M	10 Yr	OK 10 Yr
S64BM	Same as S64B plus 2 parts fungicide	<47M	10 Yr	10 Yr
S64B21	Same as S64 plus 3 parts Antioxidant 4010	>53M <61M	OK 10 Yr	OK 10 Yr
S64B100	Same as S64 plus 3 parts, N,N'-dicyclohexyl-p-phenylenediamine	>21M <27M	8 Yr	OK 10 Yr
S64B129	Same as S64 plus 3 parts Flexzone 3C	>53M <61M	OK 10 Yr	OK 10 Yr
S64B143	Same as S64 plus 3 parts Eastozone 33	>33M <40M	10 Yr	OK 10 Yr
N87	Paracril 18-80	<1W	5D	<6M
N87B33	Same as N87 plus 5 parts U.O.P. 88, 3 parts triethanolamine and 1 part wax	>6M <12M	28M	>4 Yr <5 Yr
N87B67	Same as N87 plus 5 parts Flexzone 3C and 1 part wax	>61M <67M	OK 10 Yr	<6M

NOTE: D = Days
W = Weeks
M = Months
Yr = Years
OK = Specimens crack free at time period given

Table 8
(Continued)

RIA CPD. NO.	ELASTOMER TYPE AND ANTIOZONANT	TIME TO FIRST CRACK PANAMA	ROCK ISLAND	ALASKA
N87B22	Same as N87 plus 5 parts Antioxidant 4010 and 1 part wax	OK 10 Yr	OK 10 Yr	<6M
N87B58	Same as N87 plus 5 parts, N,N'-dicyclohexyl-p-phenylenediamine and 1 part wax	>21M <27M	54M	< 6M
N87B73	Same as N87 plus 5 parts Eastozone 33 and 1 part wax	>21M <27M	10 Yr	OK 10 Yr
BIFC	Ameripol CB	<1W	5D	>6M <12M
BIFCB	Same as BIFC plus 3 parts U.O.P. 88 and 1 part wax	<1W	12M	>12M <18M
BIFCBI	Same as BIFC plus 3 parts Flexzone 3C and 1 part wax	1M	16W	>18M <24M
BIFCB2	Same as BIFC plus 3 parts Antioxidant 4010 and 1 part wax	<1W	16W	>18M <24M
BIFCB3	Same as BIFC plus 3 parts Eastozone 33 and 1 part wax	< 1W	6M	> 6M <12M
BIFCB4	Same as BIFC plus 3 parts N,N'-dicyclohexyl-p-phenylenediamine and 1 part wax	< 1W	6M	>12M <24M
N117C	Hycar 1072	> 6M <12M	16W	>6M <12M
N117CB	Same as N117C plus 5 parts U.O.P. 88 and 1 part wax	>53M <61M	OK 10 Yr	OK 10 Yr
N117CB1	Same as N117C plus 5 parts Flexzone 3C and 1 part wax	>80M <86M	OK 10 Yr	OK 10 Yr
N117CB2	Same as N117C plus 5 parts Antioxidant 4010 and 1 part wax	>53M <61M	OK 10 Yr	OK 10 Yr
N117CB3	Same as N117C plus 5 parts Eastozone 33 and 1 part wax	>40M <47M	OK 10 Yr	OK 10 Yr
N117CB4	Same as N117C plus 5 parts N,N'-dicyclohexyl-p-phenylenediamine and 1 part wax	>27M <33M	OK 10 Yr	OK 10 Yr
A11	Pale Crepe	<1W	2W	<12M
A11B7	Same as A11 plus 5 parts U.O.P. 88 and 1 part wax	>6M <12M	16W	OK 10 Yr
A11B33	Same as A11 plus 5 parts Antioxidant 4010 and 1 part wax	>6M <12M	3W	OK 10 Yr
A11B70	Same as A11 plus 5 parts Flexzone 3C and 1 part wax	>6M <12M	37M	OK 10 Yr
A11B78	Same as A11 plus 5 parts Eastozone 33 and 1 part wax	>16M <21M	28M	OK 10 Yr

Table 8
(Continued)

RIA CPD. NO.	ELASTOMER TYPE AND ANTIOZONANT	TIME TO FIRST CRACK PANAMA	ROCK ISLAND	ALASKA
A11B73	Same as A11 plus 5 parts N,N'-dicyclohexyl-p-phenylenediamine and 1 part wax	<1W	37M	>12M<18M
Z140	Nordel 1070 (EPDM)	OK 10 Yr	OK 10 Yr	---
Z144C	EPT 3509 (EPDM)	>39M<46M	OK 10 Yr	---
Z113	Nordel 1070 (EPDM)	>6M<14M	20M	
E20	Royalene 306 (EPDM)	OK 7 Yr	OK 7 Yr	---
A11A1C2	70/30 Pale Crepe/Nordel 1070	OK 5 Yr	OK 5 Yr	---
N87D4C2	70/30 Paracril 18-80/Nordel 1070	OK 5 Yr	OK 5 Yr	---
S77D10C2	70/30 SBR 1500/Nordel 1070	OK 5 Yr	OK 5 Yr	---
S211	SBR 1500	<6M	1W	---
S206-5	80/40 SBR 1500/Royalene 400	OK 5 Yr	OK 5 Yr	---
S209-1	70/30 SBR 1500/EP syn 55	OK 5 Yr	OK 5 Yr	---
S209-2	70/30 SBR 1500/Vistalon 6505	OK 5 Yr	OK 5 Yr	---
S227-2	Stereon 750 plus 5 parts U.O.P. 88 and 1 part wax	>18M<24M	42M	---
U75-1	Adiprene CM	<6M	30M	---
B33-4	HYTRANS 1227-176-2 (Alfin Rubber) plus 5 parts U.O.P. 88 and 1 part wax	>18M<24M	30M	---
S223-4	HYTRANS 1227-176-1 (Alfin Rubber) plus 5 parts U.O.P. 88 and 1 part wax	OK 4 Yr	OK 4 Yr	---

ozone specimens (ASTM D518, Method B) are cut from the vulcanizates, placed in bent loop fixtures and exposed in the 50 pphm ozone cabinet (100± 2°F) where time to first crack is determined. Vulcanizates based on SBR 1500, Paracril 18-80, and pale crepe containing U.O.P. 88, an effective chemical antiozonant, lose their ozone resistance after relatively short periods of unstressed outdoor exposure. These same elastomers, when blended with EPDM (used as a polymeric antiozonant), retain their ozone resistance after even five years of unstressed outdoor exposure. These results are shown in Table 9.

Two additional sets of bent-loop specimens were exposed outdoors in Panama, one set in the rain forest and one in the open sun. These results, given in Table 10, show that in several instances specimens cracked sooner in the rain forest than they did in the open sun.

Bent-loop specimens of numerous polyurethane vulcanizates were also exposed outdoors at Panama because it was found that stressed specimens of polyester urethane vulcanizates cracked in atmospheres of high humidity in the absence of ozone.[5] These results, given in Table 11, show that the cracking of the polyurethane specimens in Panama appears to be the rule rather than the exception and confirm previous findings by this laboratory in tests conducted under conditions of high humidity.

In addition to the determination of physical properties of the vulcanizates received from the various test sites, the appearance of the test pads was also noted by laboratory personnel at this installation. Observations made on pads received from Panama are given in Appendix B. Pads exposed at Rock Island or Alaska are much less changed in appearance than pads from Panama.

Climatological data from the three test sites for calendar year 1966 are shown in Appendix C.

CONCLUSIONS

Results indicate that aging at Panama is generally more severe than aging at Alaska or at Rock Island, Illinois, although vulcanizates based on EPR404, Chlorobutyl HT 1066, Viton B, Nordel 1070 and EPT 3509 exhibited excellent aging resistance outdoors at all three sites.

Elongation is the best criterion for measuring the aging characteristics of most vulcanizates, although tensile deterioration is the best criterion for measuring the aging resistance of cis polyisoprene, Hycar 4021 and polyester urethane vulcanizates.

Accelerated aging tests conducted at 212°F or 400°F (dependent upon the heat resistance of the vulcanizate) in general, gave a good indication of how the vulcanizates would resist outdoor aging with respect to one another, especially when elongation values were compared.

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[5] Ossefort, Z.T. and Testroet, F.B., Ibid.

Table 9
TIME TO FIRST CRACK FOR ANTIOZONANT (CHEMICAL OR POLYMERIC) INHIBITED VULCANIZATES AFTER VARIOUS PERIODS OF EXPOSURE UNSTRESSED AT ROCK ISLAND AND PANAMA

RIA CPD. NO.	ELASTOMER AND ANTIOZONANT	EXPOSURE SITE	LENGTH OF TIME EXPOSED UNSTRESSED	TIME TO FIRST CRACK IN 50 pphm OZONE CABINET BENT LOOP SPECIMEN
S64B	SBR 1500 - contains 3 parts U.O.P. 88 plus 1 part wax	Rock Island	2 Yr*	1D
		Panama	6 M	1D
S77D10C2	70/30 SBR 1500/ Nordel 1070	Rock Island	5 Yr	OK 30 D
		Panama	5 Yr*	OK 30 D
N87B33	Paracril 18-80- contains 5 parts U.O.P. 88 plus 3 parts triethanol-amine plus 1 part wax	Rock Island	2 Yr*	1D
		Panama	6 M	1D
N87D4C2	70/30 Paracril 18-80/ Nordel 1070	Rock Island	5 Yr	OK 30 D
		Panama	5 Yr*	OK 30 D
A11B7	Pale Crepe - contains 5 parts U.O.P. 88 plus 1 part wax	Rock Island	2 Yr*	1D
		Panama	6 M	1D
A11A1C2	70/30 Pale Crepe/ Nordel 1070	Rock Island	5 Yr	OK 30 D
		Panama	5 Yr	OK 30 D

*The first test pad was not removed from exposure at Rock Island until 2 years after the date the pads were placed in test.

NOTE: D = Days
M = Months
Yr = Years
OK = Specimens crack free, tests discontinued

Table 10
TIME TO FIRST CRACK FOR BENT LOOP SPECIMENS
EXPOSED OUTDOORS IN PANAMA
(RAIN FOREST VS. OPEN SUN)

RIA CPD. NO.	ELASTOMER TYPE AND ANTIOZONANT	TIME TO FIRST CRACK RAIN FOREST	OPEN SUN
Z51C	Adiprene C	OK 10 Yr	>47M <53M
Z129G	Genthane S (contains 4 parts PCD)	<6M	>6M <12M
S64	SBR 1500	<6M	<6M
S64B	Same as S64 plus 3 parts U.O.P. 88	>12M <19M	>72M <78M
S64B129	Same as S64 plus 3 parts Flexzone 3C	>19M <26M	OK 10 Yr
S64B143	Same as S64 plus 3 parts Eastozone 33	>12M <19M	>58M <65M
N87	Paracril 18-80	<6M	<6M
N87B4	Same as N87 plus 5 parts U.O.P. 88 and 1 part wax	>6M <12M	<6M
N87B67	Same as N87 plus 5 parts Flexzone 3C and 1 part wax	>47M <53M	>85M <91M
N87B73	Same as N87 plus 5 parts Eastozone 33 and 1 part wax	>6M <12M	>19M <26M
BIFC	Ameripol CB	>6M <12M	<6M
BIFCB5	Same as BIFC plus 5 parts U.O.P. 88 and 1 part wax	>12M <19M	>58M <65M
BIFCB6	Same as BIFC plus 5 parts Flexzone 3C and 1 part wax	>19M <26M	>12M <19M
BIFCB7	Same as BIFC plus 5 parts Eastozone 33 and 1 part wax	>12M <19M	>53M <58M
All	Pale Crepe	<6M	<6M
AllB7	Same as All plus 5 parts U.O.P. 88 and 1 part wax	>12M <19M	>6M <12M

NOTE: M = Months
Yr = Years
OK = Specimens crack free at time period given

Table 10
(Continued)

RIA CPD. NO.	ELASTOMER TYPE AND ANTIOZONANT	TIME TO FIRST CRACK RAIN FOREST	OPEN SUN
A11B70	Same as All plus 5 parts Flexzone 3C and 1 part wax	>19M <26M	>12M <19M
A11B78	Same as All plus 5 parts Eastozone 33 and 1 part wax	>12M <19M	>47M <53M
Z140	Nordel 1070 (EPDM) (Peroxide cure)	OK 10 Yr	OK 10 Yr
Z113	Nordel 1070 (EPDM) (Sulfur cure)	OK 7 Yr	>6M <14M
Z113D	Enjay EPT 3509 (Sulfur cure)	>33M <39M	>33M <39M
Z144C	Enjay EPT 3509 (Resin cure)	OK 7 Yr	>39M <46M
E20	Royalene 306 (EPDM) (Sulfur cure)	>6M <14M	OK 10 Yr
Z180	Hydrin 100	OK 6 Yr	OK 6 Yr
Z180-2	Hydrin 200	OK 6 Yr	>45M <50M
A11A1C2	70/30 Pale Crepe/Nordel 1070	OK 6 Yr	OK 6 Yr
N87D4C2	70/30 Paracril 18-80/Nordel 1070	OK 6 Yr	OK 6 Yr
S77D10C2	70/30 SBR 1500/Nordel 1070	OK 6 Yr	OK 6 Yr
S211	SBR 1500	<6M	<6M
S206-5	80/40 SBR 1500/Royalene 400	OK 5 Yr	OK 5 Yr
S209-1	70/30 SBR 1500/EP syn 55	OK 5 Yr	OK 5 Yr
S209-2	70/30 SBR 1500/Vistalon 6505	OK 5 Yr	OK 5 Yr
S227-2	Stereon 750 plus 5 parts U.O.P. 88 and 1 part wax	>6M <12M	>18M <24M
B33-4	HYTRANS 1227-176-2 (Alfin Rubber) plus 5 parts U.O.P. 88 and 1 part wax	>6M <12M	>18M <24M
S223-4	HYTRANS 1227-176-1 (Alfin Rubber) plus 5 parts U.O.P. 88 and 1 part wax	>6M <12M	OK 4 Yr

Table 11
TIME TO FIRST CRACK FOR BENT LOOP SPECIMENS
OF POLYURETHANE VULCANIZATES
EXPOSED OUTDOORS IN PANAMA

RIA CPD. NO.	ELASTOMER DESCRIPTION	URETHANE TYPE	TIME TO FIRST CRACK RAIN FOREST	OPEN SUN
Z51C	Adiprene C	Polyether	OK 10 Yr	>47M<53M
Z129G	Genthane S (contains 4 parts PCD)	Polyester	<6M	>6M<12M
U17-157	RIA MG-80 (peroxide cure)	Polyether/ Urea	OK 8 Yr	---
U17-165	RIA MG-80 (sulfur cure)	Polyether/ Urea	OK 8 Yr	---
U28-1	Genthane SR (contains 4 parts PCD)	Polyester	<6M	<6M
U29	Elastothane (peroxide cure)	Polyester	<6M	<6M
U29-1	Elastothane (sulfur cure)	Polyester	>40M<46M	>15M<21M
U30	Adiprene C	Polyether	>81M<87M	>70M<77M
U34	Witco MG-2 (sulfur cure)	Polyester	>15M<21M	---
U35	Genthane SR (contains unknown quantity of mfgrs. fungicide A	Polyester	>6M<12M	---
U35-1	Genthane SR (contains mfgrs. fungicide A plus 4 parts PCD)	Polyester	>6M<12M	---
U35-2	Genthane SR (contains mfgrs. fungicide A plus 4 parts TDI	Polyester	>12M<21M	---
U35-3	Genthane SR (contains unknown quantity of mfgrs. fungicide B)	Polyester	<6M	---
U35-4	Genthane SR (contains mfgrs. fungicide B plus 4 parts PCD)	Polyester	<6M	---
U35-5	Genthane SR (contains mfgrs. fungicide B plus 4 parts TDI	Polyester	>12M<21M	---
T355D	Texin 355D	Polyester	>21M<27M	---
T192A	Texin 192A	Polyester	OK 8 Yr	
T480A	Texin 480A	Polyester	>81M<87M	---

NOTE: M = Months
Yr = Years

Table 11
(Continued)

RIA CPD. NO.	ELASTOMER DESCRIPTION	URETHANE TYPE	TIME TO FIRST CRACK RAIN FOREST	OPEN SUN
U42	Cyanaprene D5	Polyester	>58M <64M	---
U43	Texin 355D	Polyester	>14M <20M	---
U43-1	Texin 480A	Polyester	>58M <64M	---
U43-2	Texin 480A (Contains unknown quantity of mfgrs. hydrolysis inhibitor)	Polyester	>33M <39M	---
U44	Niax D540	Caprolactone	>6M <14M	---
U17-226	RIA MG 1-129 (sulfur cure)	Polyether/ Urea	OK 7 Yr	---
U17-229	RIA MG 1-129 (peroxide cure)	Polyether/ Urea	<6M	----
U45	Genthane S	Polyester	>6M <14M	---
U56	Thiokol ZR625 (sulfur cure)	Polyester	>18M <24M	OK 6 Yr
U56-1	Thiokol ZR625 (sulfur cure-contains 4 parts PCD)	Polyester	>6M <13M	>18M <24M
U56-2	Thiokol ZR625 (peroxide cure)	Polyester	<6M	<6M
U56-3	Thiokol ZR625 (peroxide cure-contains 4 parts PCD)	Polyester	<6M	<6M
58300	Estane 58300	Unknown	>18M <24M	>12M <18M
58304	Estane 58304	Polyester	OK 6 Yr	>38M <45M
58013	Estane 58013	Unknown	OK 6 Yr	OK 6 Yr
U57	Upjohn [X29-83 (2092-60D)]	Polyester	>56M <62M	>24M <31M
U57-1	Upjohn CPR 2092-90A	Polyester	>50M <56M	>18M <24M
U57-2	Upjohn [X29-77A (2094-90A)]	Polyether	<6M	<6M
U75-1	Adiprene CM	Polyether	OK 4 Yr	<6M
U79	Texin 591A	Polyester	>24M <30M	>18M <24M
U79-1	Texin XP275 (contains hydrolysis inhibitor and carbon black for UV)	Polyester	OK 4 Yr	>18M <24M
U79-2	Texin 355 DXH (contains hydrolysis inhibitor)	Polyester	>12M <18M	>18M <24M
U79-3	Texin XPE-290 (contains carbon black as UV inhibitor)	Polyether	OK 4 Yr	OK 4 Yr
U79-4	Texin XPE-290 (contains UV stabilizer)	Polyether	OK 4 Yr	OK 4 Yr

The addition of one part carbon black significantly improves the tensile strength retention of SE555U high strength silicone vulcanizates during outdoor aging.

Results of exposure at Panama in a rain forest site, in a hut next to the rain forest site, and in an open sun site showed that vulcanizates based on Nordel 1070, Chlorobutyl HT 1066, Viton B, 432 Base silicone and Adiprene C exhibited good aging resistance at all three sites.

Vulcanizates based on cis polyisoprene, cis polybutadiene, and SE555U high strength silicone have significantly better age resistance when aged indoors at Rock Island than when aged outdoors at the same location. Vulcanizates based on Hycar 4021, EPR 404, Hycar 1072, and Chlorobutyl HT 1066 exhibited almost identical age resistance indoors and outdoors.

The rapid deterioration of polyester urethanes, even those containing hydrolysis inhibitors, continues to be evident in outdoor exposure at Panama. Although the original belief was that the polyether urethanes were virtually unaffected by outdoor exposure at Panama, results now indicate that significant deterioration occurs in the rain forest. Vulcanizates based on polyether urethane-urea elastomers continue to show excellent age resistance.

Stressed vulcanizates containing an EPDM polymeric antiozonant exhibit superior ozone resistance compared to vulcanizates containing a chemical antiozonant. Also, vulcanizates based on SBR 1500, Paracril 18-80, and pale crepe containing an effective chemical antiozonant lose their ozone resistance after relatively short periods of unstressed outdoor exposure (one year or less). The same elastomers, when blended with EPDM (used as a polymeric antiozonant), have retained their ozone resistance after five years of unstressed outdoor exposure.

The cracking of stressed polyurethane specimens at Panama appears to be the rule rather than the exception and confirms previous findings by this laboratory in tests conducted under conditions of high humidity.

RECOMMENDATIONS

Vulcanizates prepared from newly developed elastomeric compositions having potential military use should be exposed at Rock Island, Illinois and at Panama to determine their environmental resistance. Since arctic aging has been shown to have the least effect on the aging properties of the vulcanizates tested, no more static exposure tests of rubber vulcanizates should be conducted at Alaska. The dynamic testing of rubber end items for Army use under arctic conditions, however, is quite necessary and should not be abandoned.

Polyester urethane elastomers, even those containing hydrolysis inhibitors, should not be used in the preparation of end items for the military when a service life or storage life or more than 18 months is required.

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Appendix A

PHYSICAL PROPERTIES OF VULCANIZATES EXPOSED OUTDOORS IN ROCK ISLAND, ILLINOIS

	A21D Cis Polyisoprene			B1FC Ameripol CB			Z47F Hycar 4021			Z107 EPM MD460 (Now EPR 404)		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	2450	1300	770	2500	880	510	1590	1700	1590	2600	2500	2330
Modulus, 300%, psi	1350	930	640	1690	---	---	---	---	---	1370	1350	1560
Elongation, %	540	420	370	410	100	40	270	250	220	460	420	410
Hardness, Shore A	59	50	49	59	76	78	63	61	62	64	70	71
Strain (400 psi for 60 sec.)	137	170	226	128	58	Broke	106	100	94	157	150	147

	N117C Hycar 1072 (Carboxylic)			I38ACE Chlorobutyl HT 1066			Z83 Viton B			Z98T 432 Base Silicone (Methyl Vinyl)		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	3970	4360	3570	2070	2330	2150	2100	1900	1950	900	910	810
Modulus, 300%, psi	3420	---	---	1050	1540	1750	---	---	---	810	770	---
Elongation, %	350	260	230	570	440	390	260	260	270	370	340	280
Hardness, Shore A	82	85	82	63	69	65	77	75	75	44	50	55
Strain (400 psi for 60 sec.)	89	52	52	183	136	137	81	74	78	201	188	172

	Z60D4 Genthane SR w/TDI			S64B SBR 1500			N87B33 Paracril 18-80			M75EF Neoprene WD		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	3310	2740	2730	2600	2370	2390	1610	1640	1505	2240	1830	1840
Modulus, 300%, psi	3040	---	2730	1520	2230	---	1610	---	---	1840	1830	---
Elongation, %	330	290	300	560	340	270	300	210	160	350	300	260
Hardness, Shore A	75	76	74	62	72	73	62	74	73	51	60	62
Strain (400 psi for 60 sec.)	68	66	70	135	80	70	125	76	65	140	113	83

	Z81F LS 422 Base (Fluorosilicone)			Z56C3 SE555U (High Strength Silicone)			Z140 Nordel 1070			Z144C EPT 3509		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	690	720	630	1550	320	310	3110	2910	2580	2520	2390	2640
Modulus, 300%, psi	260	720	---	500	---	---	2040	2000	1580	1860	1940	2400
Elongation, %	690	300	260	580	200	130	390	360	410	380	340	320
Hardness, Shore A	45	64	65	49	68	67	70	73	70	72	72	74
Strain (400 psi for 60 sec.)	497	187	Broke	275	Broke	Broke	111	105	140	103	88	81

	Z116CFA3 Dynagen XP-139		
	Original	6 Years	10 Years
Tensile, psi	2680	1910	1560
Modulus, 300%, psi	1010	1560	1560
Elongation, %	670	370	300
Hardness, Shore A	62	73	72
Strain (400 psi for 60 sec.)	140	81	85

Appendix A (Continued)
PHYSICAL PROPERTIES OF VULCANIZATES EXPOSED OUTDOORS IN ALASKA

	A21D Cis Polyisoprene			B1FC Ameripol CB			247F Hycar 4021			Z107 EPM MD460 (Now EPR 404)		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	2100	2130	1700	1790	1470	1165	1290	1210	1335	2800	2720	2835
Modulus, 300%, psi	1340	1400	1405	---	---	---	---	---	---	860	900	1100
Elongation, %	470	430	340	270	140	110	220	180	190	670	620	620
Hardness, Shore A	60	64	60	62	76	78	58	62	60	60	65	66
Strain (400 psi for 60 sec.)	127	127	129	120	62	45	109	98	92	212	218	190

	N117C Hycar 1072 (Carboxylic)			I38ACE Chlorobutyl HT1066			Z83 Viton B			Z98T 432 Base Silicone (Methyl Vinyl)		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	4130	4290	4665	1950	2210	2285	1780	2050	1920	830	930	950
Modulus, 300%, psi	---	---	---	1310	1700	1715	---	2050	---	---	---	---
Elongation, %	270	180	180	490	440	450	240	300	260	250	270	250
Hardness, Shore A	88	90	89	66	68	71	74	77	75	60	60	60
Strain (400 psi for 60 sec.)	48	27	21	164	145	130	88	85	78	124	140	120

	Z60D4 Genthane SR w/TDI			S64B SBR 1500			N87B33 Paracril 18-80			M75EF Neoprene WD		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	6 Years	10 Years
Tensile, psi	3240	3300	3350	2600	2730	2380	1610	1560	1690	2240	2210	1845
Modulus, 300%, psi	3040	3130	3065	1520	2180	2315	1610	---	---	1840	2210	---
Elongation, %	340	330	320	560	430	310	300	200	200	350	300	270
Hardness, Shore A	70	76	75	62	70	71	62	72	71	51	60	59
Strain (400 psi for 60 sec.)	76	66	65	135	101	85	125	93	81	140	118	109

	Z81F LS 422 Base (Fluorosilicone)			Z56C3 SE555U (High Strength Silicone)			Z140 Nordel 1070			Z144C EPT 3509		
	Original	6 Years	10 Years	Original	6 Years	10 Years	Original	4 Years	8 Years	Original	4 Years	8 Years
Tensile, psi	690	470	470	1670	660	590	3110	2910	3020	2520	2540	2710
Modulus, 300%, psi	260	300	360	490	---	-----	2040	2440	2440	1860	2150	2335
Elongation, %	690	430	420	660	290	270	390	340	350	380	340	340
Hardness, Shore A	45	53	50	43	57	58	70	73	73	72	75	73
Strain (400 psi for 60 sec.)	497	Broke	Broke	302	230	179	111	110	96	103	88	80

	Z116CFA3 Dynagen XP-139		
	Original	4 Years	8 Years
Tensile, psi	2680	2250	2430
Modulus, 300% psi	1010	1540	1715
Elongation, %	670	440	450
Hardness, Shore A	62	72	70
Strain (400 psi for 60 sec.)	140	89	82

Appendix A (Continued)
PHYSICAL PROPERTIES OF VULCANIZATES EXPOSED OUTDOORS IN PANAMA

	Cis Polyisoprene			BIFC Ameripol CB			Z47F Hycar 4021			Z107 EPM MD460 (Now EPR404)		
	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years
Tensile, psi	2100	1150	165	1790	950	Pads	1290	1110	400	2800	2460	2375
Modulus, 300%, psi	1340	950	---	---	----	Brittle	---	---	---	860	1080	1370
Elongation, %	470	360	230	270	60		220	170	110	670	510	470
Hardness, Shore A	60	60	57	62	85		58	62	53	60	68	71
Strain (400 psi for 60 sec.)	127	153	Broke	120	Broke		109	90	Broke	212	161	155

	N117C Hycar 1072 (Carboxylic)			I38ACE Chlorobutyl HT 1066			Z83 Viton B			Z98T 432 Base Silicone (Methyl Vinyl)		
	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years
Tensile, psi	4130	4120	3810	1950	2040	2000	1780	2000	2265	830	650	505
Modulus, 300%, psi	---	---	---	1310	1610	2000	---	---	2265	---	---	---
Elongation, %	270	130	60	490	400	300	240	280	300	250	170	130
Hardness, Shore A	88	90	93	66	72	70	74	75	74	60	68	72
Strain (400 psi for 60 sec.)	48	14	10	164	123	102	88	78	82	124	111	122

	Z60D4 Genthane SR w/TDI			S64B SBR 1500			N87B33 Paracril 18-80			M75EF Neoprene WD		
	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	5 Years	10 Years
Tensile, psi	3240	Pads	---	2600	2330	1475	1610	1680	1500	2240	2340	1440
Modulus, 300% psi	3040	soft		1520	---	---	1610	---	---	1840	---	---
Elongation, %	340	and		560	240	140	300	190	110	350	250	120
Hardness, Shore A	70	tarlike		62	77	80	62	75	80	51	81	87
Strain (400 psi for 60 sec.)	75			135	53	57	125	57	50	140	31	30

	Z81F LS 422 Base (Fluorosilicone)			Z56C3 SE555U (High Strength Silicone)			Z140 Nordel 1070			Z144C EPT 3509		
	Original	5 Years	10 Years	Original	5 Years	10 Years	Original	52 Months	101 Months	Original	52 Months	101 Months
Tensile, psi	690	470	310	1670	280	355	3110	3160	2775	2520	2700	2535
Modulus, 300%, psi	260	---	---	490	---	---	2040	2400	2775	1860	2700	---
Elongation, %	690	190	230	660	140	160	390	360	300	380	300	280
Hardness, Shore A	45	68	55	43	66	68	70	73	75	72	75	75
Strain (400 psi for 60 sec.)	497	Broke	Broke	302	Broke	Broke	111	103	85	103	85	70

	Z116CFA3 Dynagen XP-139		
	Original	52 Months	101 Months
Tensile, psi	2680	1530	1065
Modulus, 300% psi	1010	1530	---
Elongation, %	670	300	190
Hardness, Shore A	62	70	74
Strain (400 psi for 60 sec.)	140	85	75

Appendix B
APPEARANCE OF TEST PADS AFTER EXPOSURE IN PANAMA

RIA COMPOUND NO.	ELASTOMER TYPE	EXPOSURE SITE	TOTAL EXPOSURE TIME	COMMENTS ON APPEARANCE
A21D	Cis Polyisoprene	Open Sun	10 Years	Profuse carbon black sloughing after 27 months which continued through entire exposure time; pad bad begun to have the feel of fine sandpaper after 7 years.
B1FC	Ameripol CB	Open Sun	7 Years	Carbon black sloughing noticeable after 5 years; pad brittle after 7 years.
Z47F	Hycar 4021	Open Sun	10 Years	Slight surface etching visible after 27 months; carbon black sloughing noticeable at 43 months; pads soft with pitted surface after 10 years.
Z107	EPM MD460 (Now EPR 404)	Open Sun	10 Years	No noticeable change in appearance until 7 years when pad surface exhibited a cracked and mottled appearance; pad surface was pitted and scaly after 10 years.
N117C	Hycar 1072	Open Sun	10 Years	Carbon black sloughing noticeable after 27 months; pad tough and hard with scaly surface after 10 years.
I38ACE	Chlorobutyl HT 1066	Open Sun	10 Years	No noticeable change until 10 years when surface appeared rough with very minute crazing.
Z83	Viton B	Open Sun	10 Years	No noticeable change until 10 years when surface had feel of fine sandpaper.
Z98T	Methyl Vinyl Silicone (432 Base)	Open Sun	10 Years	Red color of pad due to ferric oxide had faded to pink after 7 years; pad surface exposed to sun had darkened to brown and turned brittle (cracked when bent) - underside of pad was smooth and not dark or brittle.
Z60D4	Genthane SR (contains TDI)	Open Sun	5 Years	Rough and etched surface after 27 months; pads had deteriorated after 5 years to the point where they were so soft one could punch his finger through the pad.
S64B	SBR 1500	Open Sun	10 Years	Carbon black sloughing noticeable after 27 months; surface had feel of fine sandpaper after 7 years and is scaly after 10 years.
N87B33	Paracril 18-80	Open Sun	10 Years	Surface had feel of fine sandpaper after 27 months - is scaly after 10 years.
M75EF	Neoprene WD	Open Sun	10 Years	Surface badly etched and like rough sandpaper after 27 months; pad begins to curl and shrink after 43 months - is shrunken and scaly after 10 years.
Z81F	Fluorosilicone (422 base)	Open Sun	10 Years	No noticeable change in appearance after 10 years.
Z56C3	High Strength Silicone (SE555U)	Open Sun	10 Years	No noticeable change in appearance after 10 years.
Z140	Nordel 1070	Open Sun	101 Months	Slight carbon black sloughing noticeable after 101 months.
Z144C	Enjay EPT 3509	Open Sun	101 Months	No noticeable change in appearance after 101 months.
Z116CFA3	Dynagen XP-139	Open Sun	101 Months	Surface etching and carbon black sloughing noticeable after 4 years.
Z56C3T13	High Strength Silicone (SE555U) (Carbon black added for UV protection)	Open Sun	101 Months	No noticeable change in appearance after 101 months.
Z129G	Genthane S (contains PCD)	Rain Forest	18 Months	Surface cracked and badly etched and pocked after 12 months; pads deteriorated too badly to test after 18 months.
Z51C	Adiprene C	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
Z173	Hydrin 200	Rain Forest	7 Years	No noticeable change in appearance after 7 years.
U65	Vibrathane 5004 (contains PCD)	Open Sun	4 Years	Surface like that of fine sandpaper after 37 months.
U65	Vibrathane 5004 (contains PCD)	Rain Forest	3 Years	Pad in good condition after 2 years; had deteriorated too badly to test after 3 years.
S227-2	Stereon 750	Sunlight	2 Years	No noticeable change in appearance after 2 years.
S227-2	Stereon 750	Rain Forest	2 Years	Slight crazing noticeable on surface after 2 years.
U75-1	Adiprene CM	Open Sun or Rain Forest	2 Years	No noticeable change in appearance after 2 years.

Appendix B (Continued)

RIA COMPOUND NO.	ELASTOMER TYPE	EXPOSURE SITE	TOTAL EXPOSURE TIME	COMMENTS ON APPEARANCE
B33-4	HYTRANS 1227-176-2 (Alfin Rubber)	Open Sun or Rain Forest	2 Years	No noticeable change in appearance after 2 years.
S223-4	HYTRANS 1227-176-1 (Alfin Rubber)	Open Sun or Rain Forest	2 Years	No noticeable change in appearance after 2 years.
G44	Dow 746U Silicone (No postcure type)	Open Sun or Rain Forest	2 Years	No noticeable change in appearance after 2 years.
A21D	Cis Polyisoprene	Rain Forest	77 Months	Severe carbon black sloughing noticeable after 25 months.
BIFC	Ameripol CB	Rain Forest	77 Months	No noticeable change until surface cracks when bent after 77 months.
Z140	Nordel 1070	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
I38ACE	Chlorobutyl HT 1066	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
Z83	Viton B	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
Z98T	Methyl Vinyl Silicone (432 Base)	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
Z60D4	Genthane SR	Rain Forest	77 Months	Local areas soft after 34 months; pad deteriorated (soft and tarlike) too badly to test after 53 months
S64B	SBR 1500	Rain Forest	77 Months	Fine cracks in surface after 53 months; surface cracks when flexed after 77 months.
M75EFM	Neoprene WD (contains fungicide)	Rain Forest	77 Months	Surface cracks after 25 months; pad has curled and shrunk and exhibits network of cracks on surface after 77 months.
Z116CFA3	Dynagen XP-139	Rain Forest	77 Months	No noticeable change in appearance after 77 months.
Z129G	Genthane S (contains PCD)	Open Sun	4 Years	Surface badly etched after 27 months; deep pocks after 34 months; pad soft and tarlike after 4 years.
U28-1	Genthane SR (contains PCD)	Open Sun	6 Years	Surface feels like fine sandpaper after 2 years; dark spots and a few holes evident on surface after 53 months; pad soft and tarlike after 72 months.
U28-1	Genthane SR (contains PCD)	Rain Forest	34 Months	Surface soft in spots and cracks when flexed after 2 years; pad soft and tarlike after 34 months.
U29	Elastothane 455 (Peroxide cure - contains PCD)	Open Sun	7 Years	Surface finely etched after 2 years; surface like rough sandpaper after 53 months; pad soft and tarlike after 84 months.
U29	Elastothane 455 (Peroxide cure - contains PCD)	Rain Forest	53 Months	Surface cracks when flexed and soft spots in pad noticeable after 2 years; pad soft and tarlike after 53 months.
U29-1	Elastothane 455 (Sulfur cure - contains PCD)	Open Sun	28 Months	Pad soft and tarlike after 28 months.
U29-1	Elastothane 455 (Sulfur cure - contains PCD)	Rain Forest	53 Months	Pad soft after 2 years; pad soft and tarlike after 53 months.
U30	Adiprene C	Open Sun	6 Years	Slight carbon black sloughing after 6 years.
U30	Adiprene C	Rain Forest	7 Years	Slight carbon black sloughing after 7 years.
U31	Genthane S (contains mfgrs. fungicide plus PCD)	Rain Forest	53 Months	Local areas crack when flexed after 34 months; pad soft and tarlike after 53 months.
U35	Genthane SR (contains mfgrs. fungicide A)	Rain Forest	28 Months	Soft and gummy after 18 months; tarlike after 28 months.

Appendix B (Continued)

RIA COMPOUND NO.	ELASTOMER TYPE	EXPOSURE SITE	TOTAL EXPOSURE TIME	COMMENTS ON APPEARANCE
U35-1	Genthane SR (contains mfgrs. fungicide A plus PCD)	Rain Forest	34 Months	Slight pitting and etching of surface after 18 months; cracks when flexed after 28 months; soft and tarlike after 34 months.
U35-2	Genthane SR (contains mfgrs. fungicide A plus TDI)	Rain Forest	53 Months	Etching and pocking of surface noticeable after 34 months; soft and tarlike after 53 months.
U35-3	Genthane SR (contains mfgrs. fungicide B)	Rain Forest	34 Months	Pad soft and surface etching visible after 18 months; soft and tarlike after 34 months.
U35-4	Genthane SR (contains mfgrs. fungicide B plus PCD)	Rain Forest	53 Months	Etching and pocking of surface noticeable after 34 months; soft and tarlike after 53 months.
U35-5	Genthane SR (contains mfgrs. fungicide B plus TDI)	Rain Forest	90 Months	Local surface areas crack when bent after 53 months; entire surface stiff and cracks when bent after 6 years; pad deteriorated too badly to test after 90 months.
U34	Witco MG 2	Rain Forest	39 Months	Pad soft after 2 years, tarlike after 39 months.
U42	Cyanaprene D5	Rain Forest	51 Months	Pad turned brown from cream color after 1 year; pad tough; surface cracks when bent after 39 months; pad brittle after 51 months.
U43	Texin 355 D	Rain Forest	64 Months	No noticeable change after 64 months.
U43-1	Texin 480A	Rain Forest	64 Months	Surface cracks when flexed after 58 months; pad brittle after 64 months.
U43-2	Texin 480A (Hydrolysis inhibitor added)	Rain Forest	64 Months	No noticeable change after 64 months.
U44	Niax D 540	Rain Forest	51 Months	Appeared in good shape after 39 months; too badly deteriorated to test after 51 months.
U45	Genthane S (contains TDI)	Rain Forest	51 Months	Surface etched and pocked after 27 months; pad soft after 39 months; tarlike after 51 months.
U17-226	RIA MG 1-129 (Sulfur cure)	Rain Forest	64 Months	No noticeable change after 64 months.
U17-229	RIA MG 1-129 (Peroxide cure)	Rain Forest	64 Months	No noticeable change after 64 months.
U56	Thiokol ZR 625 (Sulfur cure)	Open Sun	51 Months	Surface like that of sandpaper after 38 months; soft and tarlike after 51 months.
U56	Thiokol ZR 625 (Sulfur cure)	Rain Forest	63 Months	Pad slightly soft after 51 months; soft and tarlike after 63 months.
U56-1	Thiokol ZR 625 (Sulfur cure plus PCD)	Open Sun	63 Months	Surface like sandpaper after 38 months; surface rougher after 63 months.
U56-1	Thiokol ZR 625 (Sulfur cure plus PCD)	Rain Forest	63 Months	Pad soft, surface cracks when bent after 63 months.
U56-2	Thiokol ZR 625 (Peroxide cure)	Open Sun	63 Months	Surface like fine sandpaper after 26 months; pad soft and tarlike after 63 months.
U56-2	Thiokol ZR 625 (Peroxide cure)	Rain Forest	51 Months	Surface like fine sandpaper and cracks when bent after 26 months; pad soft and tarlike after 51 months.
U56-3	Thiokol ZR 625 (Peroxide cure plus PCD)	Open Sun	63 Months	Surface like that of sandpaper after 51 months; slightly rougher feel after 63 months.

Appendix B (Continued)

RIA COMPOUND NO.	ELASTOMER TYPE	EXPOSURE SITE	TOTAL EXPOSURE TIME	COMMENTS ON APPEARANCE
U56-3	Thiokol ZR 625 (Peroxide cure plus PCD)	Rain Forest	51 Months	Surface like fine sandpaper, cracks when bent after 26 months; pads soft and tarlike after 51 months.
58300	Estane 58300	Open Sun	38 Months	Pad brittle after 38 months.
58300	Estane 58300	Rain Forest	38 Months	Pad brittle after 38 months.
58304	Estane 58304	Open Sun	63 Months	Surface like rough sandpaper after 63 months.
58304	Estane 58304	Rain Forest	63 Months	No noticeable change after 63 months.
58013	Estane 58013	Open Sun	63 Months	Slight carbon black sloughing after 63 months.
58013	Estane 58013	Rain Forest	63 Months	No noticeable change after 63 months.
U57	Upjohn X29-83 (2092-60D)	Open Sun	50 Months	Surface like fine sandpaper after 14 months; pad brittle after 50 months.
U57	Upjohn X29-83 (2092-60D)	Rain Forest	50 Months	No noticeable change in appearance after 50 Months.
U57-1	Upjohn CPR 2092-90A	Open Sun	50 Months	Surface like fine sandpaper after 14 months; pad brittle after 50 months.
U57-1	Upjohn CPR 2092-90A	Rain Forest	50 Months	No noticeable change after 50 months.
U57-2	Upjohn X29-77A (2094-90A)	Open Sun	50 Months	Surface feels like fine sandpaper after 14 months; rougher after 50 months.
U57-2	Upjohn X29-77A (2094-90A)	Rain Forest	50 Months	No noticeable change after 50 months.
U79	Texin 591A	Open Sun	25 Months	Color turned from ivory to brown/black after 12 months; pad brittle after 25 months.
U79	Texin 591A	Rain Forest	37 Months	No noticeable change in appearance after 37 months.
U79-1	Texin XP 275 (contains hydrolysis inhibitor and carbon black for UV)	Open Sun	37 Months	Surface like that of fine sandpaper after 25 months.
U79-1	Texin XP 275 (contains hydrolysis inhibitor and carbon black for UV)	Rain Forest	37 Months	No noticeable change after 37 months.
U79-2	Texin 355 DXH (contains hydrolysis inhibitor)	Open Sun	37 Months	Color turned from ivory to brown after 12 months; pad brittle after 37 months.
U79-2	Texin 355 DXH (contains hydrolysis inhibitor)	Rain Forest	37 Months	Color turned from ivory to brown after 37 months.
U79-3	Texin XPE-290 (contains carbon black for UV)	Open Sun	37 Months	Carbon black sloughing after 25 months.
U79-3	Texin XPE-290 (contains carbon black for UV)	Rain Forest	37 Months	No noticeable change after 37 months.
U79-4	Texin XPE-290 (contains UV stabilizer)	Open Sun	37 Months	Slight yellowing from ivory color after 25 months; deeper yellow after 37 months.
U79-4	(Texin XPE-290 (contains UV stabilizer)	Rain Forest	37 Months	Sight yellowing from ivory color after 25 months; deeper yellow after 37 months.

Appendix B (Continued)

RIA COMPOUND NO.	ELASTOMER TYPE	EXPOSURE SITE	TOTAL EXPOSURE TIME	COMMENTS ON APPEARANCE
U83, U83-1, U83-2, U83-3, U83-4, U83-5 and U83-6	Upjohn urethanes	Open Sun or Rain Forest	12 Months	Only noticeable change thus far is slight yellowing of pads from original ivory color.
S211	SBR 1500	Open Sun	4 Years	Slight carbon black sloughing noticeable after 4 years.
S211	SBR 1500	Rain Forest	4 Years	No noticeable change after 4 years.
S206-5	80/40 SBR 1500/ Royalene 400	Open Sun	4 Years	Slight carbon black sloughing noticeable after 4 years.
S206-5	80/40 SBR 1500/ Royalene 400	Rain Forest	4 Years	No noticeable change after 4 years.
S209-1	70/30 SBR 1500/ EP syn 55	Open Sun	4 Years	Slight carbon black sloughing noticeable after 4 years.
S209-1	70/30 SBR 1500/ EP syn 55	Rain Forest	4 Years	No noticeable change after 4 years.
S209-2	70/30 SBR 1500/ Vistalon 6505	Open Sun	4 Years	Slight carbon black sloughing noticeable after 4 years.
S209-2	70/30 SBR 1500/ Vistalon 6505	Rain Forest	4 Years	No noticeable change after 4 years.
A11A1C2	70/30 Pale Crepe/ Nordel 1070	Open Sun or Rain Forest	4 Years	No noticeable change after 4 years.
S77D10C2	70/30 SBR 1500/ Nordel 1070	Open Sun	4 Years	Slight carbon black sloughing after 4 years.
S77D10C2	70/30 SBR 1500/ Nordel 1070	Rain Forest	4 Years	No noticeable change after 4 years.
N87D4C2	70/30 Paracril 18-80/ Nordel 1070	Open Sun	4 Years	Pronounced carbon black sloughing after 4 years.
N87D4C2	70/30 Paracril 18-80/ Nordel 1070	Rain Forest	4 Years	No noticeable change after 4 years.

Appendix C

1966 CLIMATOLOGICAL DATA FOR ALASKA[1], PANAMA[2], AND ROCK ISLAND, ILLINOIS[3]

	Average Monthly Temperature, °F				Total Precipitation (Inches of Water)				Average Relative Humidity, %			
1966	Alaska	Rock Island	Panama (Sun)	Panama (Rain Forest)	Alaska	Rock Island	Panama (Sun)	Panama (Rain Forest)	Alaska (2 PM AST)	Rock Island (Noon CST)	Panama (Sun)	Panama (Rain Forest)
Jan	-27.4	14.3	81	80	0.01	2.01	2.14	1.50	84	66	87	90
Feb	- 7.6	24.8	81	80	1.75	0.89	0.71	0.64	87	63	83	85
Mar	- 2.5	39.2	80	78	0.34	0.85	1.85	2.44	66	58	83	84
Apr	27.1	47.0	80	78	0.32	3.96	7.26	8.70	50	57	83	89
May	45.4	56.3	77	77	0.38	6.39	22.87	18.30	48	52	93	98
Jun	63.3	70.5	76	80	0.19	4.25	4.49	4.24	34	54	90	96
Jul	62.5	77.9	78	78	0.83	7.74	16.57	11.80	37	52	93	97
Aug	57.1	70.6	80	77	0.59	0.77	19.90	19.80	43	53	94	100
Sep	50.1	62.9	79	79	0.15	2.80	15.15	11.25	42	52	93	99
Oct	24.3	52.5	78	78	0.29	4.38	16.01	19.62	65	46	93	99
Nov	0.6	41.7	77	78	2.06	1.12	33.50	34.76	78	61	93	99
Dec	-20.1	28.1	78	78	0.16	2.52	18.40	14.65	80	70	92	98

[1]Data taken from U.S. Department of Commerce, Weather Bureau, Climatological Data Sheets for Fairbanks, Alaska, International Airport

[2]Data taken from "Interim Report No. 4 by Frankford Arsenal on Material Specimens from Rock Island Arsenal that are Exposed at Tropical Test Sites in the Panama Canal Zone," dated 12 May 1967.

[3]Data taken from U.S. Department of Commerce, Weather Bureau, Climatological Data Sheets for Moline, Illinois, Quad City Airport.

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Ten-Year Aging Of Elastomeric Vulcanizates In Panama, Alaska, And Illinois

Prepared By: Edward W. Bergstrom

Technical Report R-TR-74-038

73 Pages, Incl Figures

Vulcanizates prepared from commercially available elastomers, many of which have been introduced since 1955, were exposed outdoors in Alaska; Rock Island, Illinois; and in the Panama Canal Zone to compare the effects of exposure in aretic, temperate, and tropic environments. Aging data collected on pads exposed as long as ten years are presented. The effects of rain forest vs. open sun exposure in Panama are compared as well as the effects of indoor vs. outdoor aging at Rock Island, Illinois.

The ozone resistance of numerous vulcanizates was determined by exposures at the three sites, using ASTM D518, Method B, bent loop specimens. The resistance to cracking of numerous polyurethane vulcanizates exposed in Panama was also measured.

Results show that aging is generally more severe in Panama than in Alaska or Rock Island, although some vulcanizates exhibit excellent aging resistance at all three sites.

Polymeric antiozonants (EPDM) are more effective than chemical antiozonants in protecting SBR, NBR, and NR vulcanizates from ozone attack.

1. Elastomers
2. Environmental Aging
3. Outdoor Aging
4. Ozone Resistance
5. Exposure Cracking
6. Antiozonants
7. Properties, General

I. Edward W. Bergstrom
II. Rock Island Arsenal
III. Research Directorate
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